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THIN FILM SOLAR CELL MODULE DEVELOPMENT, CADMIUM SULFIDE CELL

by

F. A. Blake, and M. R. Stahler

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FINAL REPORT

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by

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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THIN FILM SOLAR CELL MODULE DEVELOPMENT - CADMIUM SULFIDE CELL

by F.A. Blake and M.R. Stahler

General Electric Co., Space Systems

SUMMARY

The objective of this contractual effort was to pursue a concentrated development effort to: (1) provide two methods for joining cadmium sulfide thin film solar cells into modules of twenty-five cells each, (2) test and prove these methods, (3) develop processes for the production fabrication of array modules, and (4) fabricate eight solar cell modules by these processes. A six-step program was carried out in support of this objective and included;

a. Experimental evaluation of methods to obtain low-resistance, mechanically strong and stable series interconnection joints.

b. Experimental evaluation of methods of attaining stable parallel interconnections.

c. Selection of two substantially different methods for series and parallel interconnection and mechanical joining.

d. Qualification testing of varied module sizes to establish the structural integrity required to survive the specified dynamic (roll tests), tensile, and vacuum thermal cycling tests.

e. Process development to convert laboratory techniques to efficient production fabrication practices including the construction of an assembly fixture for the twenty-five cell modules.

f. Demonstration of the manufacturing processes by producing eight twenty-five cell modules, four by each method of interconnection, suitable for use as elements in a rollup solar cell array.

The methods by which the modules were fabricated were a soldered electrical interconnection with mechanical reinforcement and a conductive, epoxy-bonded joint forming the electrical interconnection and mechanical joint. The relatively weak solder interconnection required a reinforcement system to shunt tension loads around it, thus leaving it virtually immune to mechanical stress, whereas the conductive epoxy bonded joint inherently had sufficient mechanical strength. Both methods exceeded the technical goals covering series joint resistance and structural integrity, but both fell short of the added-weight technical goal. Performance with regard to joint thickness was divided, the conductive bonded joint being slightly thinner than its goal while the soldered joint was slightly thicker than its goal.

THIN FILM SOLAR CELL MODULE DEVELOPMENT,

CADMIUM SULFIDE CELL

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ABSTRACT

Two methods for the series and parallel interconnection of cadmium sulfide thin film solar cells into modules have been developed and qualified. Soldered or conductive epoxy joining processes can be used with either of two separate electrical paralleling configurations to produce modules of low joint resistivity, low weight, and high mechanical strength. Mechanical loading of the soldered electrical joint is avoided by floating it between two load bearing paths. Sample submodules of the various configurations have exceeded the requirements of specialized dynamic, tensile, and vacuum thermal cycling tests. Processes and tooling have been developed and used for the efficient fabrication of both soldered and bonded modules of 25 cells each.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND AND PROGRAM GOALS

Cadmium Sulfide solar cell development programs over the last several years have resulted in a lightweight flexible cell (Figures 1-1 and 1-2) with sufficiently high performance that near term application of the cells in a rollup solar array is a reality. Interconnection of pairs of cells and of engineering models up to forty square feet have been accomplished by Lewis Research Center. As a result, the need was apparent for an engineering effort directed specifically at the development and qualification of interconnection methods for CdS solar cells. Such a program would keep the application technology abreast of the cell technology.

The Thin Film Solar Cell Module Development Program was planned and performed around the objectives of (1) developing two separate methods for joining of CdS thin film solar cells into modules of twenty-five cells each, (2) testing and proving of these methods, (3) developing processes for the production fabrication of array modules, and (4) fabrication of eight solar cell modules by these processes. The original contract called for joining methods to be developed for both the Clevite plastic substrate and Harshaw metal substrate cells. Shortly after the experimental program began, however, the requirments pertaining to the Harshaw cell were deleted and the effort on the Clevite cell expanded.

Modules suitable for use as elements in a roll-up solar array were manufactured using each of two methods, one utilizing soldering to obtain the electrical interconnection and one using a conductive epoxy bond to obtain the electrical interconnection. The soldered method, shown in crossection in Figure 1-3, required a mechanical reinforcement and support system which would shunt any tension loads around the relatively weak electrical joints, leaving it virtually immune to stress. The relatively greater joint strength of the conductive epoxy bond permitted a simpler construction (Figure 1-4) with the result that the actual thickness of the bonded joint was 0.011 inch compared to 0.018 inch for the reinforced soldered joint.

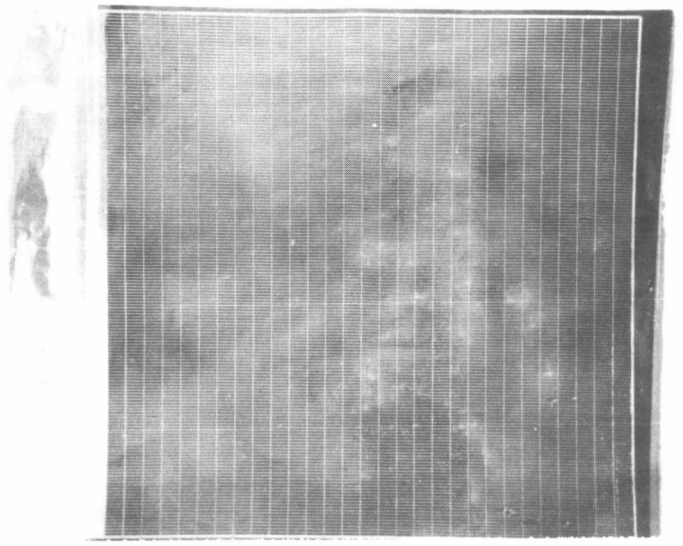


Figure 1-1. Clevite Plastic Substrate CdS Solar Cell

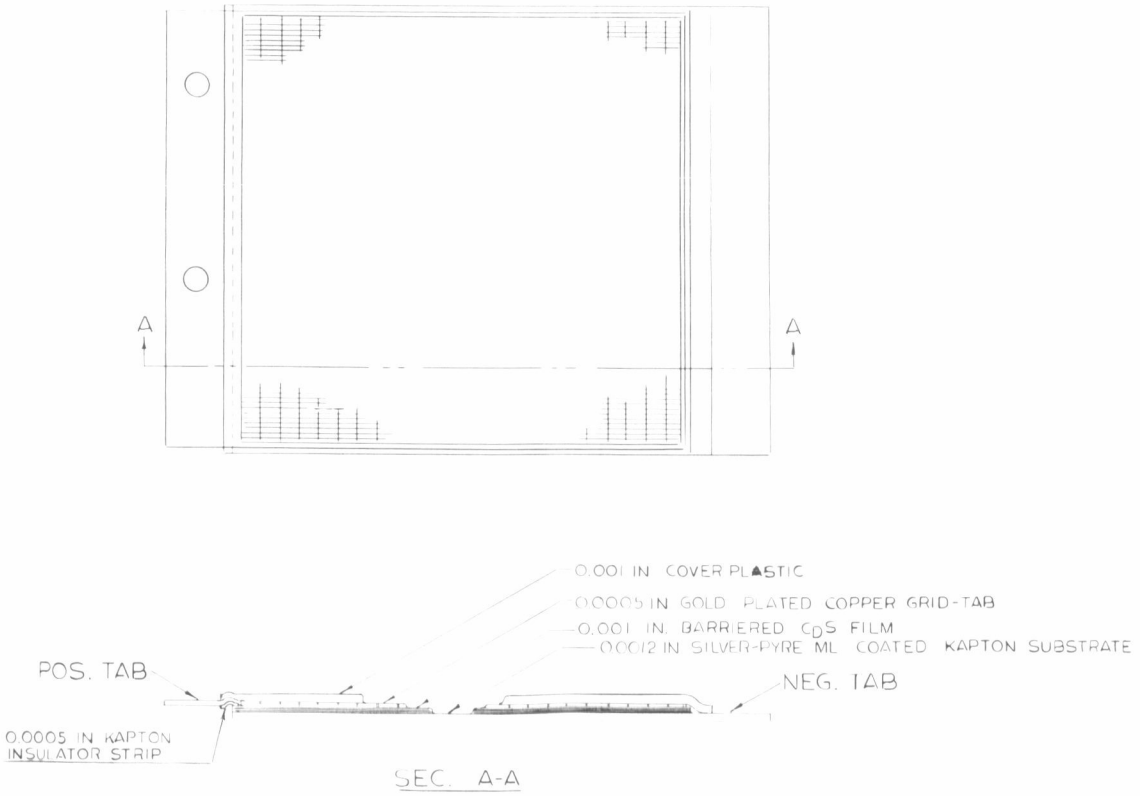


Figure 1-2. Clevite Plastic Substrate Cadmium Solfide Solar Cell

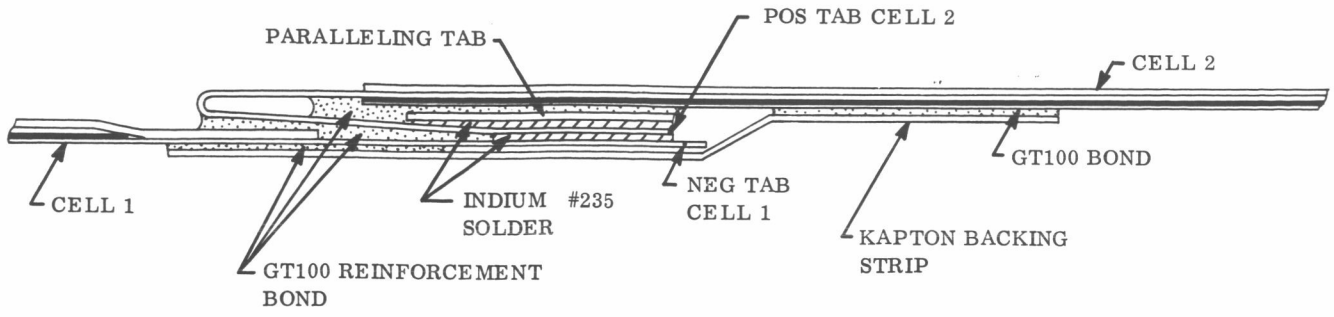


Figure 1-3. Cross Section of Reinforced Soldered Interconnection Method

Figure 1-4. Cross Section of Conductive Epoxy Bonded Interconnection Method

Two methods of cell-to-cell parallel interconnection were established as suitable for the CdS solar array modules by the testing programs. The preferred paralleling method and the one used on the twenty-five cell modules is the "Inline- Tab Connected" design shown in Figure 1-5. The parallel connection is obtained by use of a 0.188 inch by 3.00-inch tab of copper clad mylar which spans the parallel joint.

The alternate parallel interconnection is the "Staggered Cell" design shown in Figure 1-6. This approach does not add an element to the joint as does the inline tab, method but its dependence on the cell end tabs for cross flowing current results in a parallel direction resistance approximately five times higher than the "Inline" interconnection.

Goals for the electrical connection and mechanical joining methods were:

a. A maximum electrical connection between two cells in series of 0.008 ohm.

b. An added weight per cell edge of 0.03 gram or less.

c. An added thickness of 0.0025 inch maximum for each adhesive tape use.

d. A cured thickness of 0.002 inch maximum for each layer of adhesive.

e. The structural integrity required for survival of specified dynamic, tensile, and vacuum thermal cycling tests.

1.2 PROGRAM PLAN

A six-step program was carried out in support of the "Thin Film Solar Cell Module Development."

1.2.1 SERIES JOINT EXPERIMENTAL PROGRAM

Experimental evaluation of such series joining methods as soldering, conductive, epoxy bonding, and direct bonding (welding) was performed on cell segments, and full size cell samples. The evaluation included conductivity, roll test, and tensile test performance.

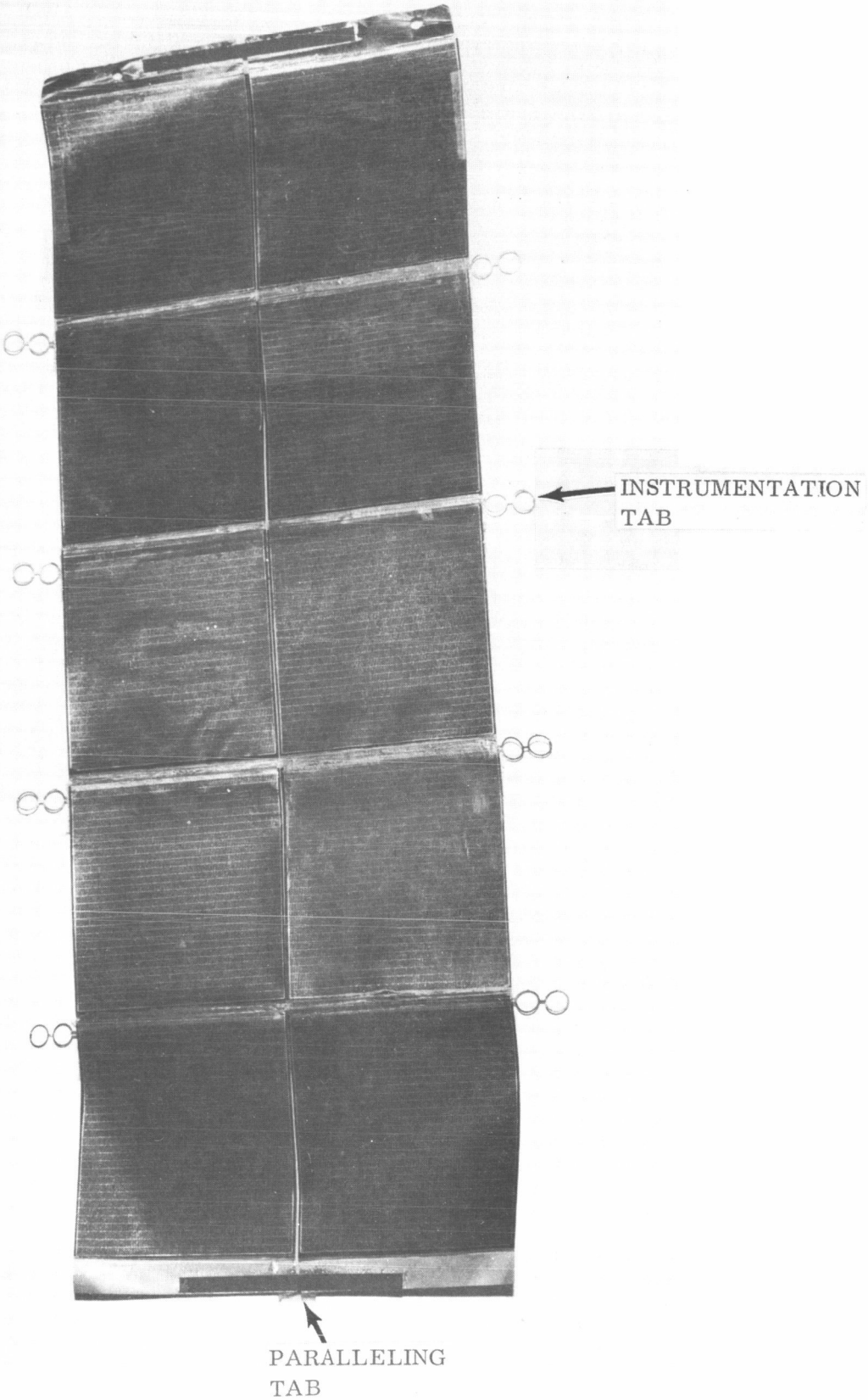


Figure 1-5. 2 Cell Parallel x 5 Cell Series Test Sample, "Tab-Connected Inline" Paralleling Method

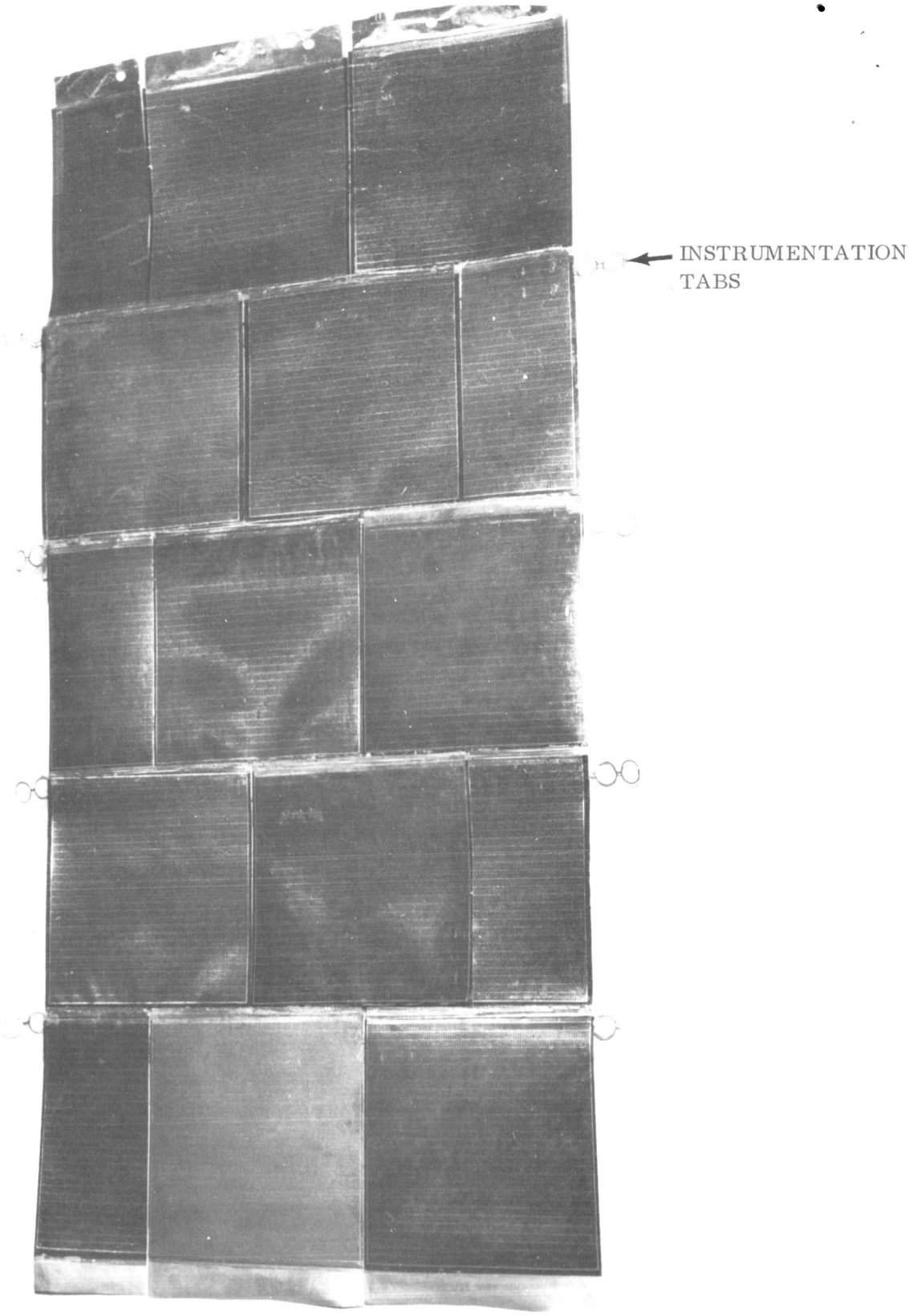


Figure 1-6. 2-1/2 Cell Parallel x 5 Cell Series Test Sample, "Half Cell Staggered" Paralleling Method

1.2.2 PARALLEL JOINT EXPERIMENTAL PROGRAM

Experimental evaluation of parallel interconnection was performed using the "Tab Connected Inline" method using copper foil, photo etched BeCu, and Schjel Clad L5550 tabs, and, "Staggered Cell" paralleling with both 1 cm and half cell staggering. Again, evaluation included conductivity, roll test, and tensile test performance.

1.2.3 METHODS SELECTION

Selection of 2 substantially different methods for both series and parallel electrical interconnection and mechanical joining offered an alternate method for every phase of the module fabrication process.

1.2.4 QUALIFICATION TESTING

Based on the results of the experimental program, a matrix of testing activities required was established to demonstrate qualification in accordance with the specialized dynamic, tensile, and vacuum thermal cycling test effects on test samples. The set of qualification test configurations specified in the work statement and the tests applicable to each are;

a. 1 parallel x 2 series - Tensile Test, Series Direction

b. 2 parallel x 2 series - Tensile Test, Parallel Direction

c. 1 parallel x 5 series - Primary Roll Test, Tensile Test, Series Direction

d. 2 parallel x 5 series - Primary and Secondary Roll Test, Tensile Test, Series Direction

e. 5 parallel x 2 series - Primary Roll Test, Tensile Test, Parallel Direction

f. 2 parallel x 2 series - Vacuum Thermal Cycling, 24 Cycles $-70^{o}C$ to $+55^{o}C$ then 8 hours at high temperature ($55^{o}C$) dwell

A complete set of samples of the above test configurations was tested for both the reinforced soldered joint and the conductive epoxy bonded joint, each using the "Tab Connected Inline" paralleling method. Additionally, a partial set of reinforced soldered "Half Cell Staggered" parallel interconnection samples was subjected to the applicable tests.

1.2.5 MANUFACTURING ENGINEERING AND TOOLING

Manufacturing process planning and tool design activity required to produce the twenty five (25) cell modules of the types represented in the Qualification program was performed in parallel with the qualification program. The module fabrication equipment (Figure 1-7) was predominantly governed by the soldering process requirements, but included the assembly fixture on which the bonded modules were assembled.

1.2.6 MANUFACTURE OF THE 25 CELL MODULES

Eight modules of twenty five cells each (Figure 1-8) were assembled, performance tested, and delivered to the customer. Four were built using the reinforced soldered joint method and four were built by the conductive epoxy bonded joint method. Performance variation between units of each method was extremely small as was the variation between methods.

Development of the interconnection methods and the corresponding manufacturing processes required to combine individual CdS solar cells into a 25 cell module were successful. Results obtained during the performance of the six segments of the program are presented in the following sections of this final report.

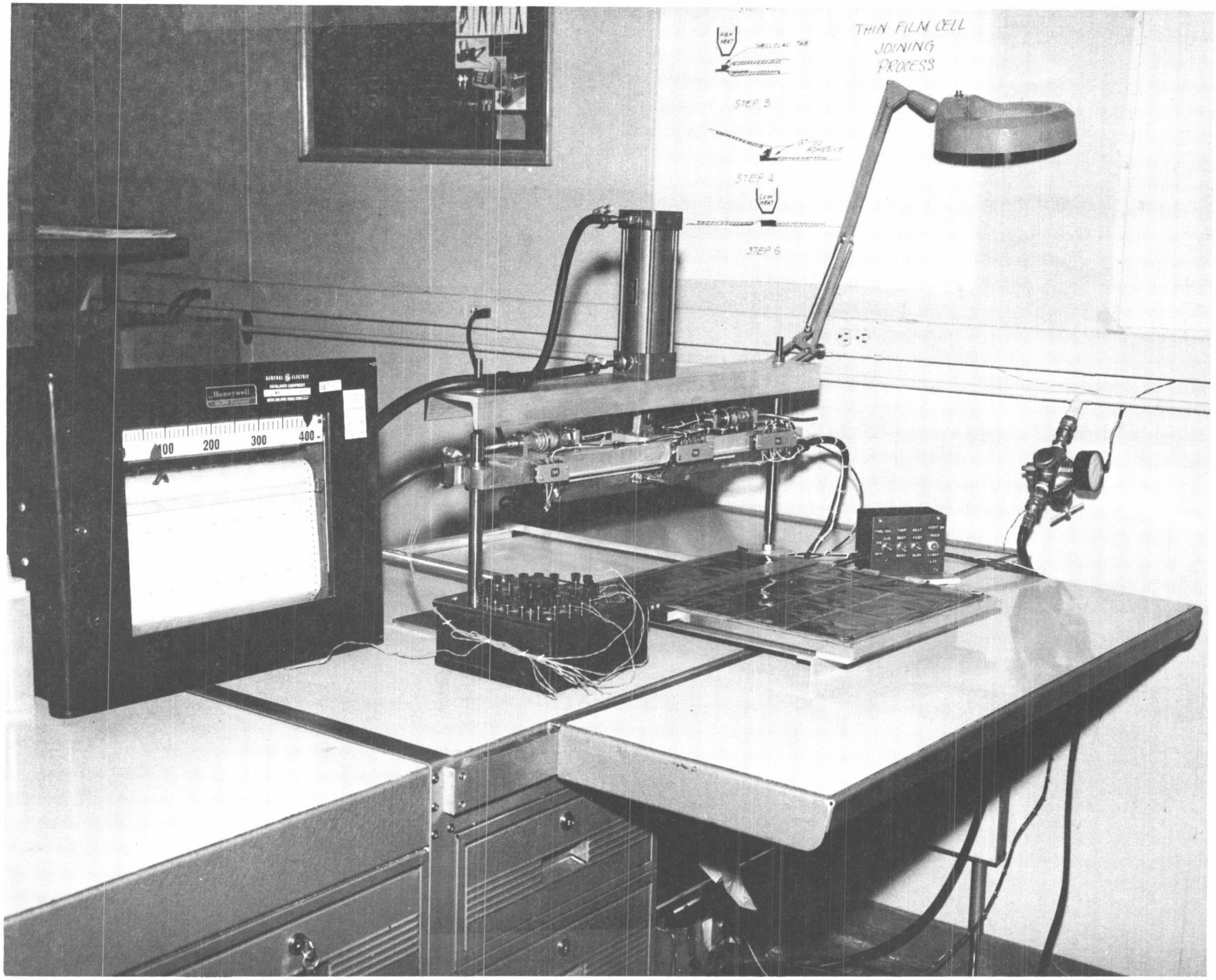


Figure 1-7. Module Fabrication Equipment for 25 Cell Modules

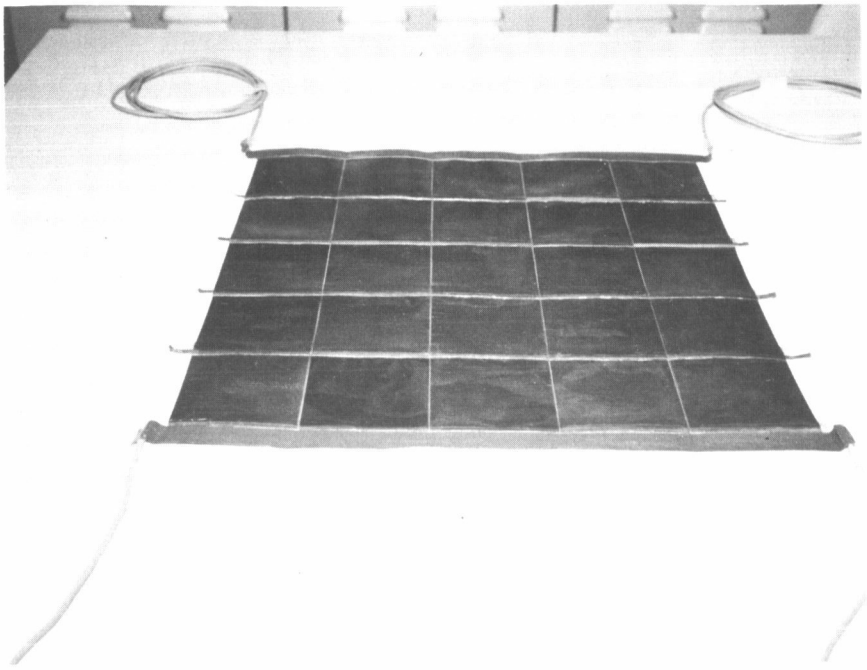


Figure 1-8. Twenty-Five Cell CdS Solar Cell Module P/N 47D 214515, S/N 1

SECTION 2

CONCLUSIONS AND SUMMARY OF RESULTS

2.1 ATTAINMENT OF PROGRAM OBJECTIVES

The objectives of the program, (1) developing two separate methods for the joining of CdS thin film solar cells into separate solar cell array modules of twenty-five (25) cells each, (2) testing to prove these methods, (3) the development of processes for the production fabrication of array modules, and (4) the fabrication by these processes of eight (8) modules have been accomplished. The methods involve soldering and appropriate joint reinforcement and conductive epoxy bonding.

2.2 ATTAINMENT OF TECHNICAL GOALS

2.2.1 INTERCONNECTION CONDUCTIVITY

Goal: To produce interconnections having less than 0.008 ohm resistance in series.

Result: Both the soldering and conductive bonding processes consistently produced interconnections which measured below 0.001 ohm. Even after compensation for current path effects on the measured data, the resistance values were always below 0.0044 ohm. The range of values for the soldered interconnections is slightly lower than the range of values for the conductive bonded interconnections, but the area of overlap of the ranges is so large that the resistance performance must be considered to be equal for the two methods.

2.2.2 ADDED WEIGHT OF INTERCONNECTIONS

Goal: The added weight of interconnections to be 0.03 gram per cell edge maximum. (This scales up to 3 grams per twenty five cell module).

Result:	Soldered Joint	Conductive Bonded Joint
Added Wt of Interconnections in 25 cell modules, grams	12.18 (Avg of 4 mods)	6.23 (Avg of 4 mods)

2.2.3 JOINT THICKNESS

Goal: To maintain joint thickness increments within 0.002 inch for adhesive layers, and within 0.0025 inch for adhesive tape layers.

Results: The stated goal results in a total thickness goal of 0.016 inch for the reinforced soldered joint and a thickness goal of 0.0135 inch for the conductive epoxy bonded joint. The soldered joint failed to meet the goal by 0.0026 inch nominally, while the conductive bonded joint was within the goal by 0.0024 inch nominally.

2.2.4 MECHANICAL STRENGTH

Goal: Achieve the structural integrity required to survive specialized dynamic, tensile, and vacuum thermal cycling tests.

Result: Both configurations exceed the mechanical strength requirements by a wide margin (margins of safety of 5 to 7 referenced to 5 pound test load). Conductive bonded modules are stronger initially than the soldered modules (55 pound versus 46 pound/series row, avg) and are more stable with regard to preservation of that strength in a flexing environment (zero weakening versus 17.4 pound tensile strength reduction, avg).

2.3 ELECTRICAL PERFORMANCE

Electrical performance of the twenty-five cell modules of each configuration is so nearly identical that it must be considered to be equal. This is shown by the standardized efficiency data obtained from the solar test which averaged 2.346 percent for the soldered modules and 2.365 percent for the conductive bonded modules. Another parameter which is obtained directly from the observed data, the fill factor (peak power divided by the product of the short circuit current times the open circuit voltage), shows similarly identical performance; 0.614 for the soldered modules and 0.622 for the conductive bonded modules.

2.4 AREA UTILIZATION FACTOR

The design of the module has resulted in an area utilization factor of 0.842 (active cell area/total module area) which is significant in that any measureable improvement would require a change in cell design.

2.5 FABRICATION COMPLEXITY

Both types of modules can be manufactured efficiently as demonstrated by the manufacturing labor expended on the final units of each, 10 hours for the fourth soldered module and 14 hours for the fourth conductive bonded module. From the manufacturing standpoint the soldered unit requires more operations, but they are generally short time operations requiring less skill and concentration than the bonding operations.

SECTION 3

EXPERIMENTAL INTERCONNECTION METHODS EVALUATION

3.1 SERIES INTERCONNECTION

3.1.1 CONDUCTIVITY

Achieving an interconnection between adjacent CdS solar cells which introduced no more than eight (8) milliohms resistance in the series path was a prime objective of the program. The initial evaluation of the candidate joining techniques against this requirement was the first step of the experimental program. Cell segments, 16 mm wide, were joined by soldering using Indium-Bismuth Alloy No. 235 solder and by EP3026 conductive epoxy. (Use of cell segments at the start of the program was done for material conservation rather than technical reasons and allowed an earlier start of development activities and instrumentation check out.) As shown in Table 3-1, cell segment testing showed that the interconnection resistances attainable from either the soldering or conductive bonding processes were well below the 8 milliohm goal.

Table 3-1. Summary of Cell Segment Series Interconnection Resistance Testing

Sample No.	Interconnection Method	Observed Resistivity 16 mm wide interconnection Milliohms	Extrapolated Resistivity For Full Width Cell (72.2 mm) Milliohms
1, 2, 3 Avg. (Plastic Cell)	Indium Solder ($156^{o}C$ T_{melt})	6.63	1.47
8, 9, 10, 11 Avg. (Plastic Cell)	Indium-Bismuth No. 235 Alloy Solder ($151^{o}C$ T_{melt})	4.68	1.04
12, 13 Avg. (Harshaw Cell)	Indium-Bismuth No. 235 Alloy Solder ($151^{o}C$ T_{melt})	1.32	0.29
4, 5, 6, 7 Avg. (Plastic Cell)	EP 3026 Conductive Epoxy	14.12	3.13

Joint resistance data were obtained throughout the program with instrumentation in accordance with the schematic of Figure 3-1. A regulated voltage was supplied to the circuit and the voltage across the load resistor was monitored with a digital voltmeter to establish the current flowing in the circuit. Taps on either side of the contact were monitored on a 10 mv full scale recorder, resulting in a sensitivity range of 1 milliohm per inch with 1 amp power current to 10 milliohms per inch with 0.1 amp. As 0.05 inch accuracy was readily attainable visually, data were accurate to 0.05 milliohm in the most sensitive range.

3.1.2 MECHANICAL STRENGTH, SERIES JOINT

Two specialized dynamic tests, the Primary Roll Test, and the Secondary Roll Test were specified in the contract. The principal mechanical strength goal of the contract was to attain joints which would enable test samples to survive these tests without degradation. Both tests consisted of cycling the assembled module back and forth over a two (2) inch diameter roller while under a five (5) pound tension load a minimum of 100 times. The rate of travel over the roller was specified as 1 ± 0.3 ft/sec. The difference in the tests was in the side of the cell in contact with the roller. The active surface of the cell faced outward during the Primary Roll Test, and inward during the Secondary Roll Test.

The test fixture to accomplish the Roll Tests is shown schematically in Figure 3-2 and pictorially in Figure 3-3. The five pound tension load was provided by a Neg'ator spring. Cycling actuation was manual, with a one second count per stroke providing the required speed of travel.

Further data on structural strength performance were obtained from the Ultimate Tensile Test. This test was performed on nearly all test samples built during the program and while there was no specified limit to which the results were referenced, the results did enable overall strength comparison between the candidate methods and did establish the strength margin over the specified tensions of the roll and vacuum thermal cycling test requirements. The Ultimate Tensile Test installation is shown pictorially in Figure 3-4. Elongation data for a 2 inch section spanning one joint is obtained by use of the dial indicator. Leads to measure the voltage drop across each of the joints are evident in the photograph.

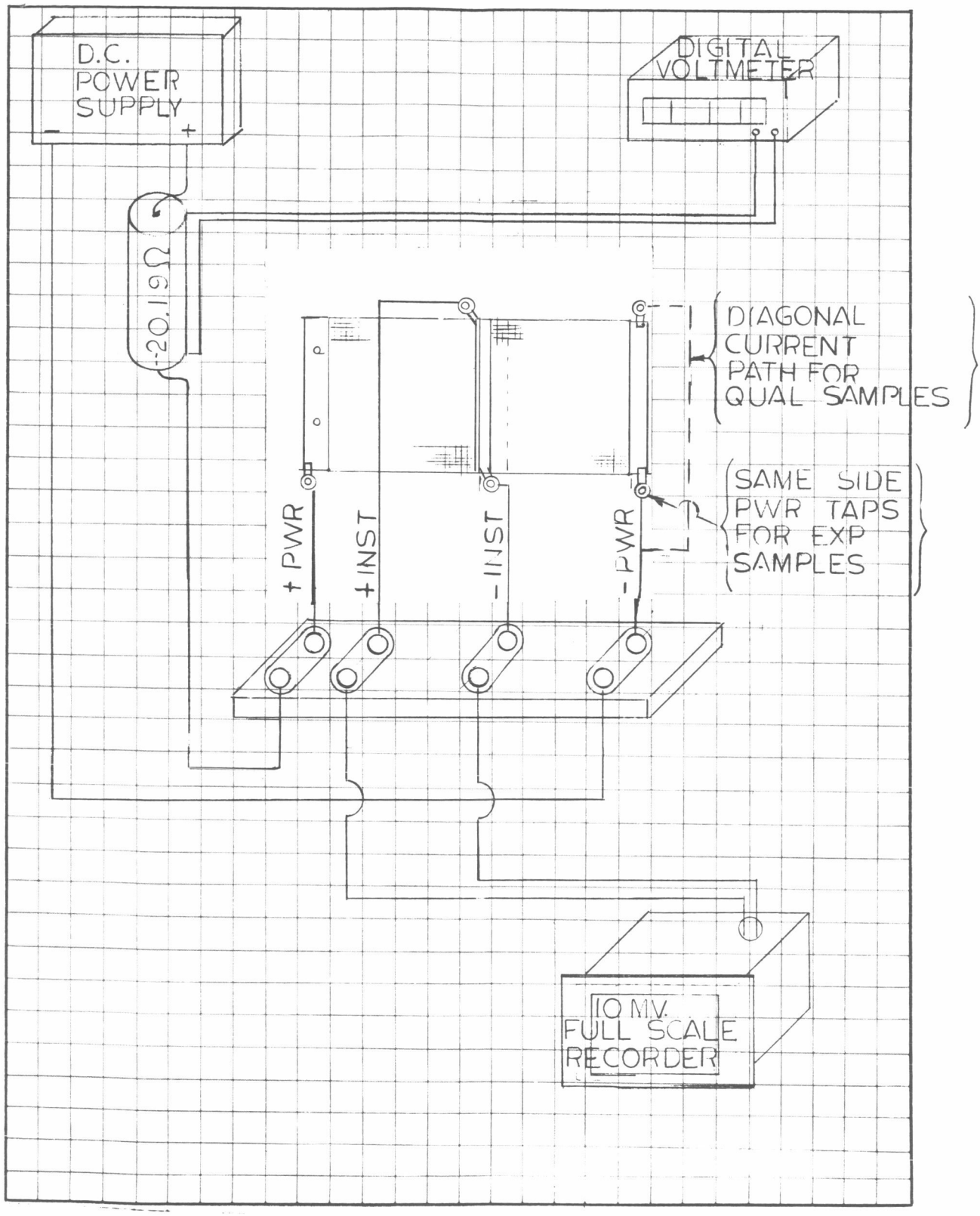


Figure 3-1. Resistivity Instrumentation Schematic

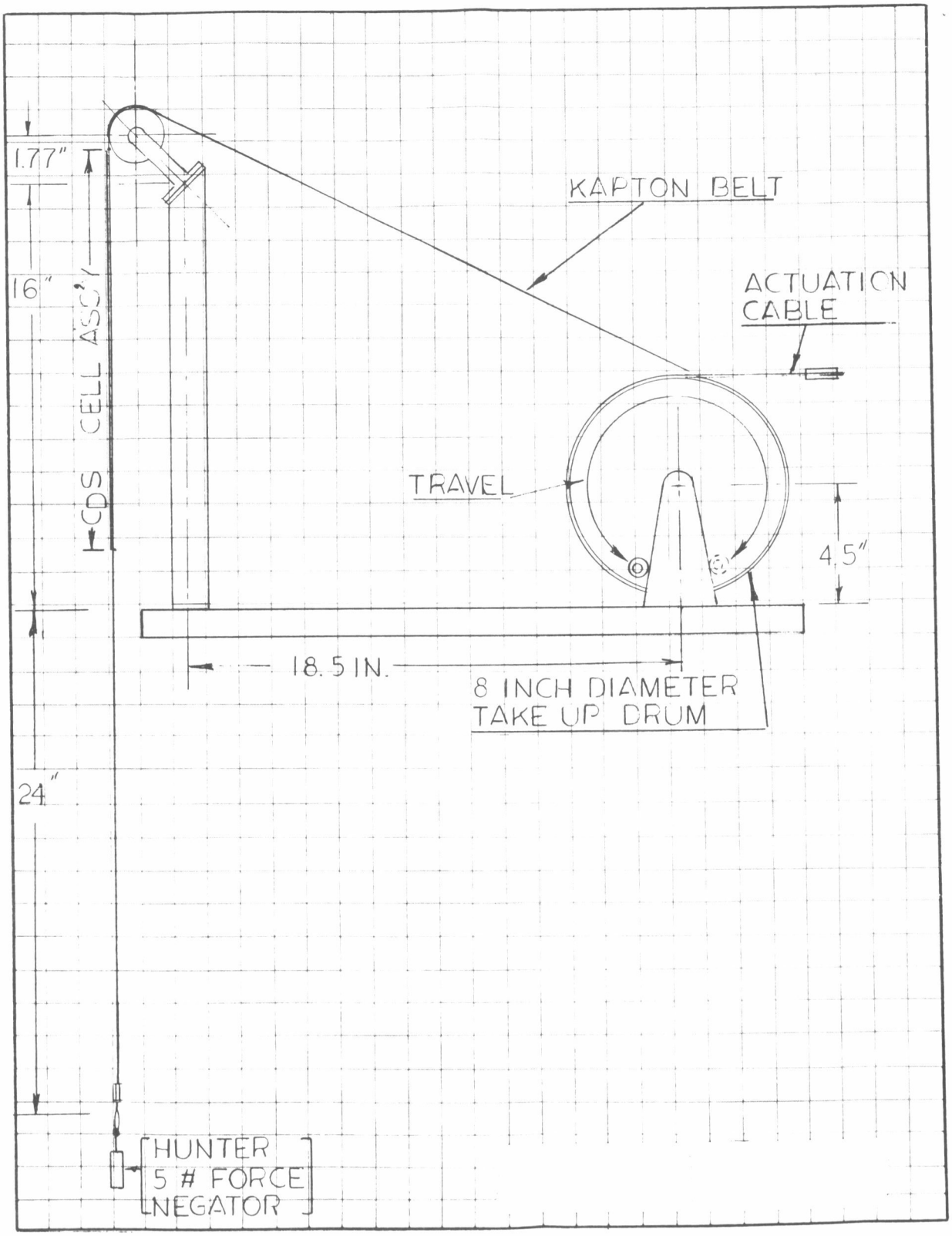


Figure 3-2. Roll Test Installation Schematic

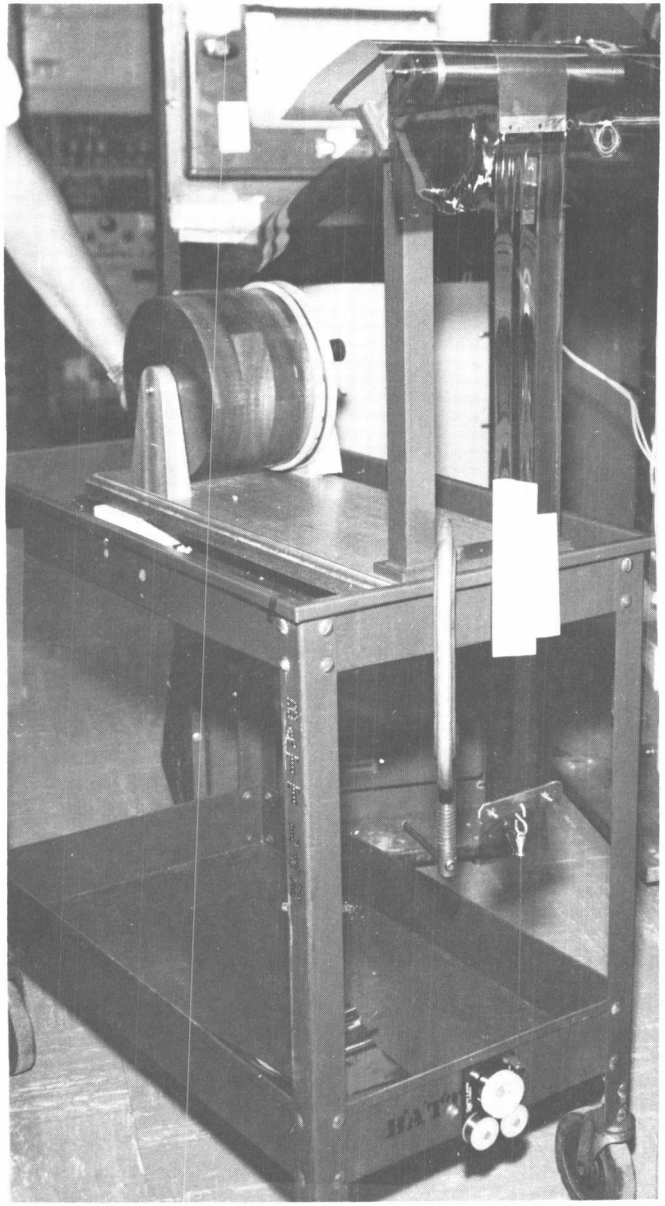


Figure 3-3. Roll Test Fixture - CdS Thin Film Solar Cell Test Samples

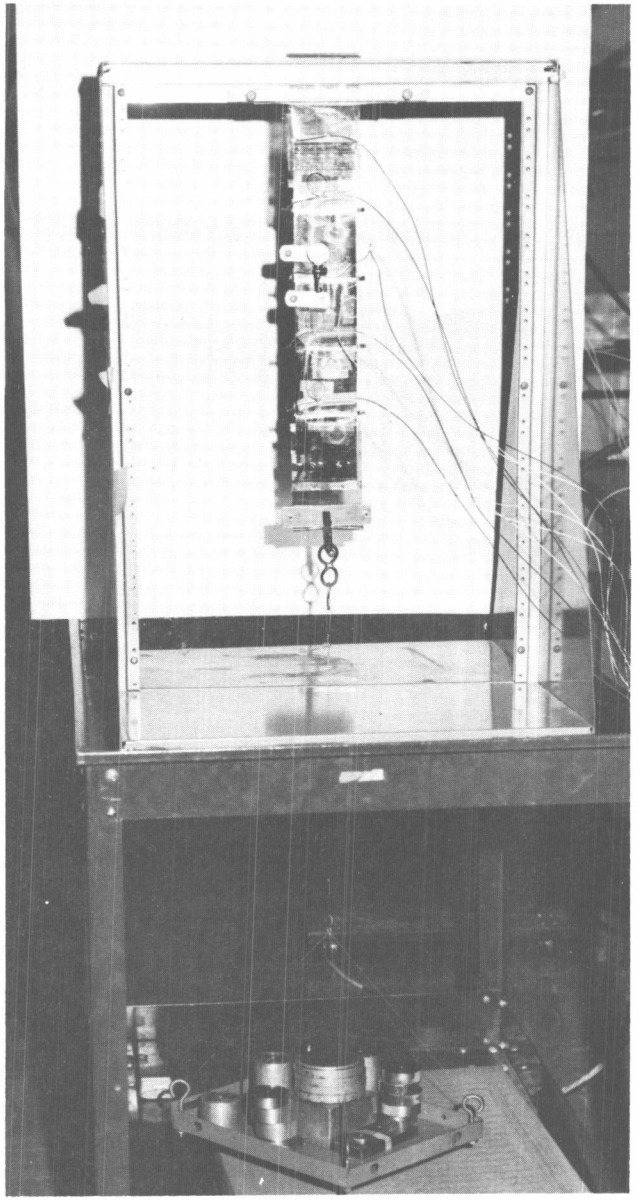


Figure 3-4. Ultimate Tensile Test Installation - CdS Thin Film Solar Cell Test Sample

The second segment of the experimental program was the evaluation of full-cell test samples for conductivity and for mechanical strength as determined by the Roll and Ultimate Tensile Strength tests. Two-cell samples were made up for this activity which allowed covering the spectrum of candidates with the least expenditure of cells.

Due to the unknown structural stability of the interconnected cells at the start of the program, two general methods were specified to be among the candidates evaluated, (1) "Common Substrate" in which the interconnected cells were adhesive bonded to a continuous sheet of Kapton which would become the major mechanical load carrying member, and (2) "Butt Joint" a term used to describe the construction where cells formed the array sheet and were themselves the load carrying members. Early joints were tested for stability both ways, first while mounted on the substrate and secondly after the substrate had been cut away in the area of the joint thus forcing the joint to carry the mechanical load.

3.1.2.1 Reinforced-Soldered Series Joint

Initial soldered electrical connections failed because the bond between the solder and the plastic (negative) cell tab had very low mechanical strength. Subsequently, improved versions (using partial reinforcement with GT100 and "complete reinforcement" which included use of a Kapton backing strip), required in the contract, resulted in high strength soldered electrical connections. In the completely reinforced design, the electrical connection was floated between two load bearing paths. This final configuration of the soldered butt-joint is shown in Figure 3-5. One mechanical load path is provided by bridging the back of the interconnection with a 1 mil thick x 5/8 inch wide strip of Kapton bonded to the backs of the cells by GT100, a Schjeldahl thermoplastic adhesive. The other load path is from the front of the Number 1 cell through a layer of GT100 to the folded positve tab of the Number 2 cell and then through another layer of GT100 to the back of the Number 2 cell. Figure 3-6 shows the sequence of assembly events used during the experimental program to obtain the reinforced soldered joint. Note that this same method of reinforcement was used for the resistance welded joint.

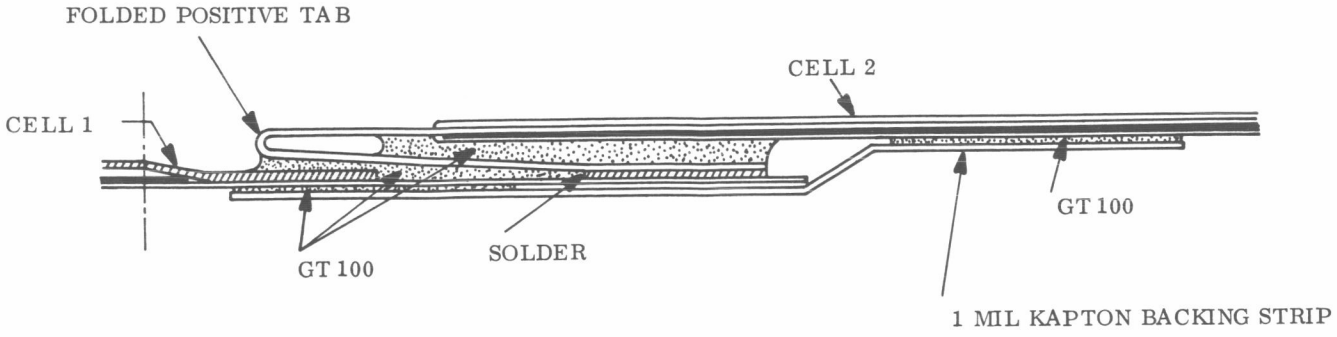
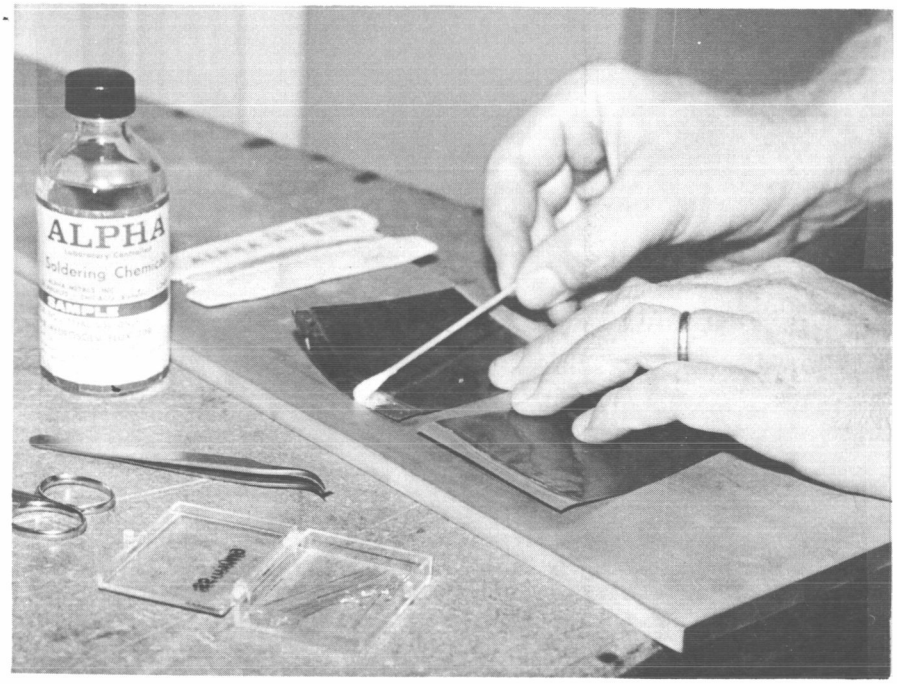


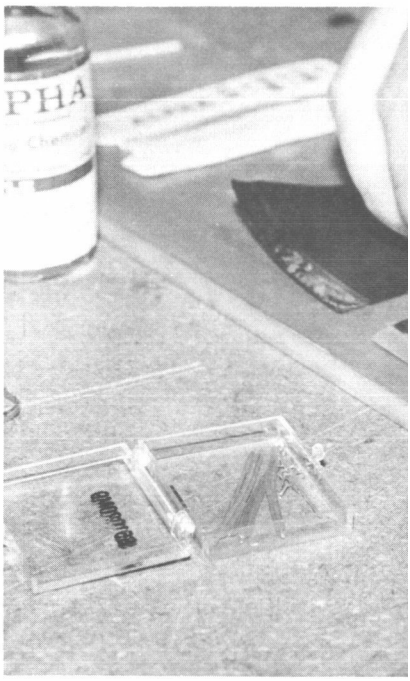
Figure 3-5. Reinforced Soldered Series Joint

Conductivity performance for the two In-Bi (No. 235 Alloy) soldered joints, Samples 16 and 17 (Figure 3-7) exceeded the extrapolated performance predicted from the segment tests. Initial series joint resistivities of 0.49 and 0.30 milliohm were observed, as shown in Table 3-2, illustrating a wide margin of performance improvement beyond the 8 milliohm goal. The stability of the electrical joint is illustrated by the data taken after the primary and secondary roll tests with the common substrate and after the subsequent secondary and primary roll tests with the butt joint configuration. Conversion of the common substrate samples to butt joint samples was by cutting away of the common substrate between joint reinforcements.

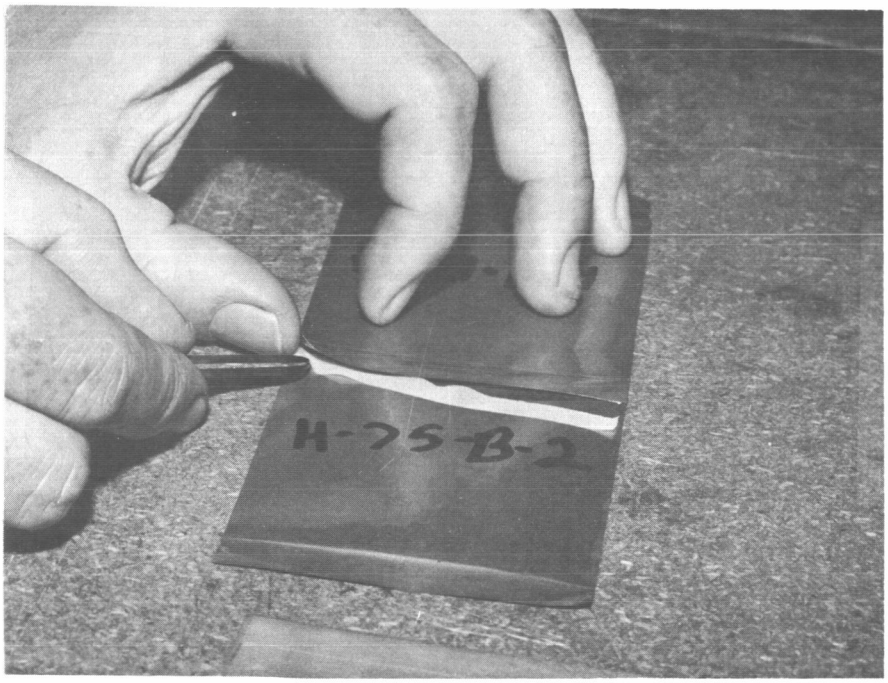
Ultimate tensile strength margins of safety of 3 were evident from the butt joint configurations even after having been subjected to the 400 cycles of roll testing. (Note: Margin of safety = factor of safety -1.)



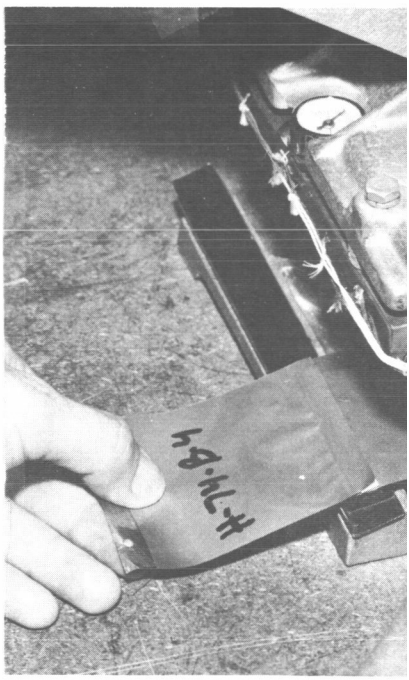
(a) Flux Application



(b) Insertion of Indium

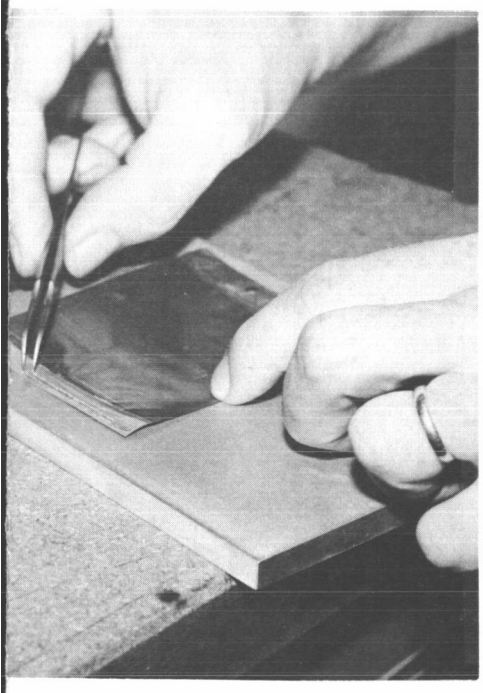


(d) Fold-Back of Positive Tab and Insertion of GT100

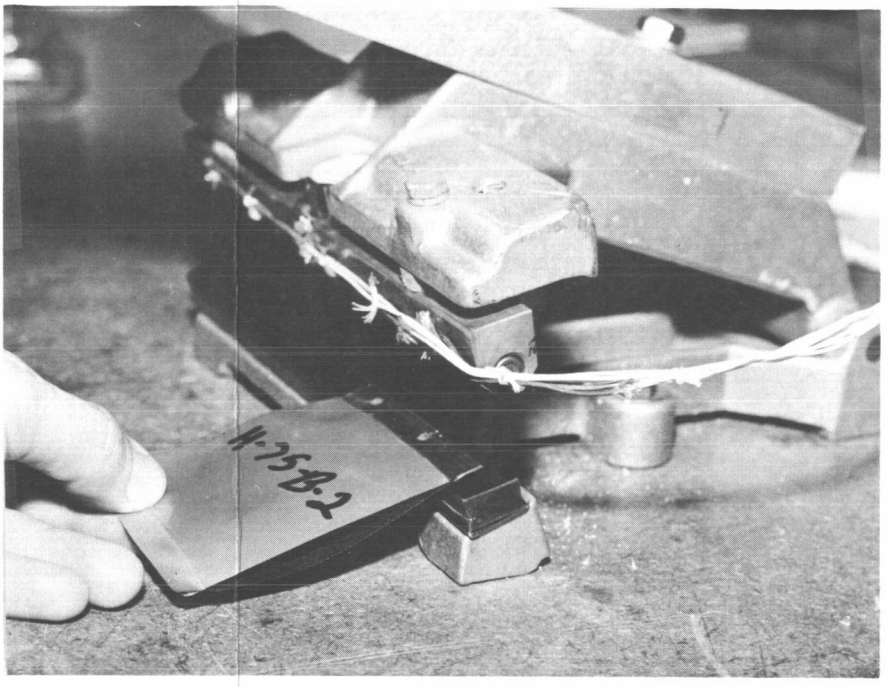


(e) Fold-Ba

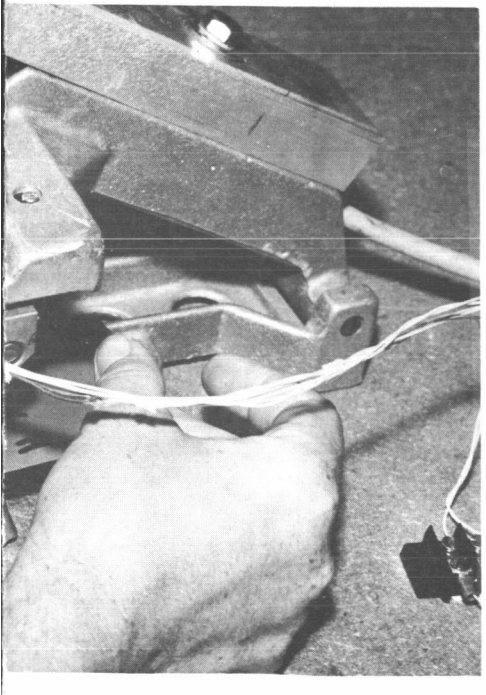
FOLDOUT FRAME 1



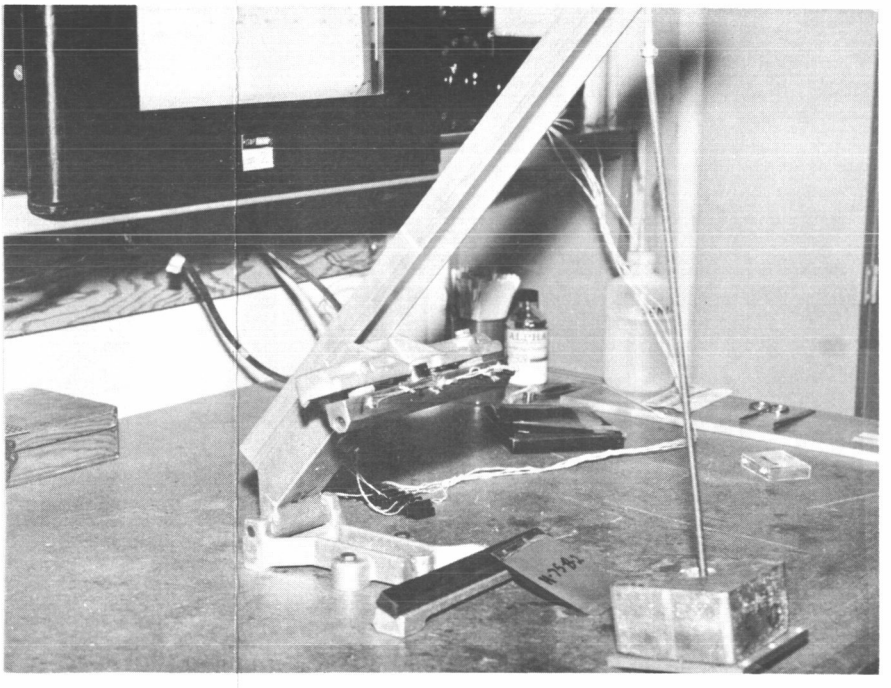
-Bismuth Solder Preforms



(c) Soldering and Reinforcement Bonding Operation



k Bonding Operation



(f) Soldering Station Used for Experimental Joint Assembly

Figure 3-6. Sequence of Assembly Events for Reinforced Soldered Joint

FOLDOUT FRAME

FOLDOUT FRAME 2

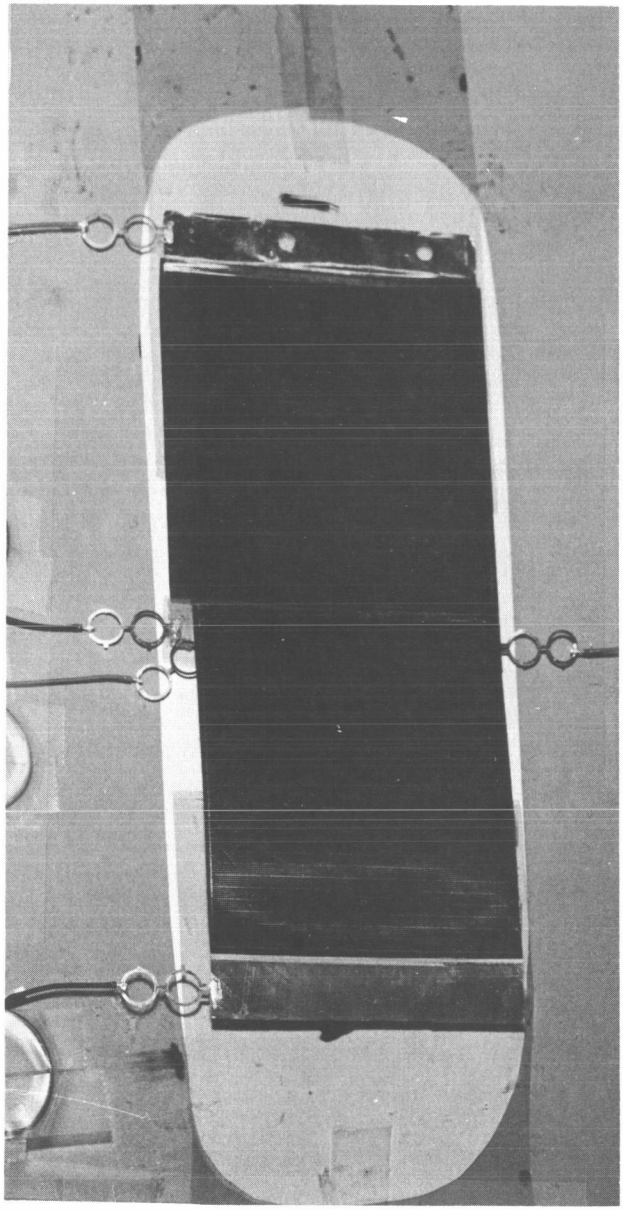


Figure 3-7(a). Sample 17, Clevite Cells GT100-Reinforced, No. 235 In-Bi Soldered Series Joint

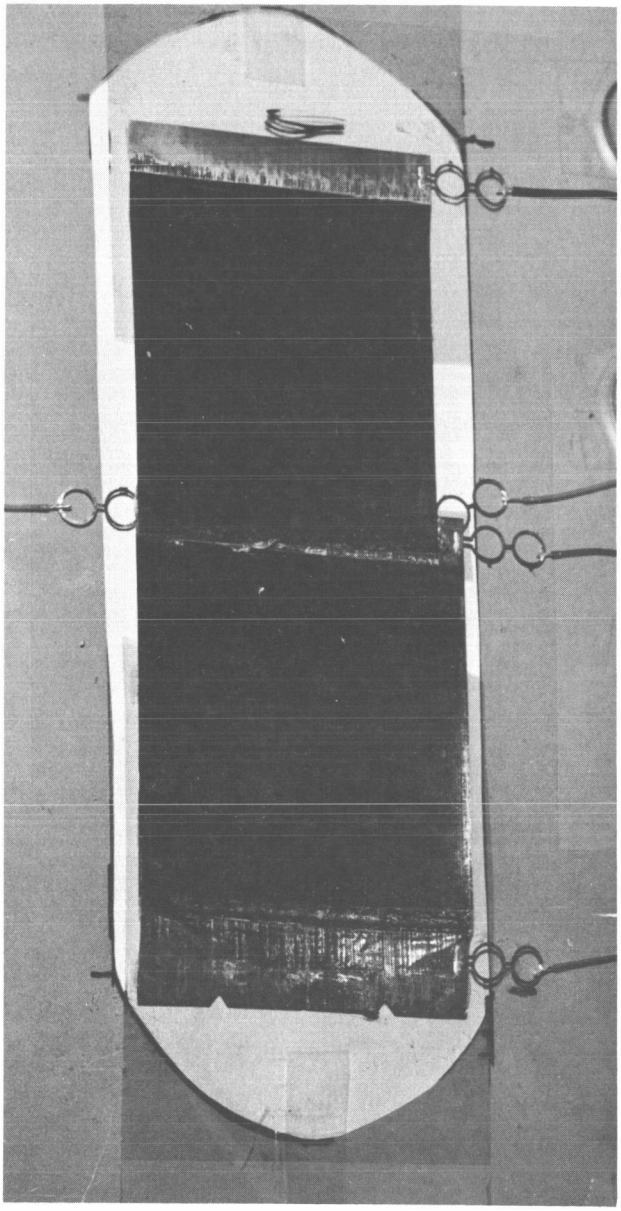


Figure 3-7(b). Sample 18, Harshaw Cells GT100-Reinforced, No. 235 In-Bi Soldered Series Joint

Figure 3-7. Whole Cell Series Joint Samples

Table 3-2. Summary of Series Joint Performance - Primary and Secondary Roll Cycling; Ultimate Tensile Strength

Sample No., Type	Series Joint Resistance - Milliohms - (Contractual Goal = 8 milliohms max)					Ultimate Tensile Test Load, Pounds
	Initial	Post Prim. Roll Common Substrate	Post Sec. Roll Common Substrate	Post Sec. Roll Butt Joint	Post Prim. Roll Butt Joint	
16, Clevite Cells No. 235 In-Bi Solder GT100 Reinforcement*	0.49	0.46	0.47	0.46	0.46	20 (Butt Joint)*
17, Clevite Cells No. 235 In-Bi Solder GT100 Reinforcement*	0.30	0.28	0.29	0.31	0.40	19 (Butt Joint)*
18, Harshaw Cells No. 235 In-Bi Solder GT100 Reinforcement*	0.10	0.10	0.10	0.10	0.11	30+ (Butt Joint)*
19, Clevite Cells EP3026 Cond. Epoxy	0.28	0.25	0.22	0.24	0.21	25 (Butt Joint)*
20, Clevite Cells SMRD 745-50% Ag Conductive Epoxy	0.47	0.50	0.75	0.75	0.75	30 (Butt Joint)*
21, Clevite Cells EP3026 Cond. Epoxy	0.97	0.95	0.81	No Test	No Test	39 (Common Substrate)
22, Clevite Cells SMRD 745-50% Ag	0.84	0.84	0.85	No Test	No Test	43 (Common Substrate)
23, Clevite Cells Resistance Weld GT100 Reinforcement*	0.94	1.14	1.30	1.78	1.70	19 (Butt Joint)*
24, Clevite Cells Resistance Weld GT100 Reinforcement*	1.36	1.43	1.48	No Test	No Test	No Test

*GT100 in direct layer between positive and negative tabs. Butt joint samples did not have Kapton backing strip used in later qual program samples and 25 cell modules.

3.1.2.2 Conductive Epoxy Series Interconnection and Joint

Two types of conductive epoxy were evaluated for their suitability in the CdS cell interconnection application. The first, Epoxy Products EP3026 had been previously utilized in a similar cell interconnection program.[1] The second was a 50-50 blend by weight of General Electric SMRD 745 Flexible Epoxy[2] and Alcan Silver Flake, a combination experimented with at the Lewis Research Center. The SMRD 745 had previously been found to be a good adhesive for joining Kapton, one of the requirements of the material used in the CdS cell joint. As can be noted from Table 3-2 the conductivities observed for the conductive epoxy samples were slightly lower than those observed from the soldered samples, but were well within the program goal. As with the soldered samples the electrical interconnections shows extreme stability during the roll tests.

Ultimate Tensile Test results showed the conductive epoxy butt joints to be 15 - 30 percent stronger than the reinforced soldered butt joints. An additional strength capability of at least 30 percent was exhibited by the common substrate samples, with demonstrated margins of safety referenced to the 5 pound test load requirement of 7 and above. The SMRD 745 + 50% Ag material was preferred over the EP3026 because of the resultant joint thicknesses, a factor apparently tracing back to the viscosity of the epoxy mix. The EP3026 joints were approximately 0.006 inch thicker than the joints with the SMRD 745-Ag mixture.

3.1.2.3 Resistance Welded GT100-Reinforced Series Joint

Series electrical interconnection by means of parallel gap resistance welding was accomplished and complete joints were fabricated using the reinforcement technique previously described for the soldered joints.

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1. Tech Rep. AFAPL-TR-67-42 "Thin Film Photovoltaic Cell Array Investigation" R.W. Aldrich, et al.

2. SMRD 745 Flexible Conductive Epoxy is available from:
   G.E. Space Systems Operation
   Spacecraft Material Research and Development Section
   P.O. Box 8555, Philadelphia, Pa., 19101

3.1.2.3.1 Welding Process Description

The heat produced by the resistance of materials to be joined to the flow of an electrical current is combined with a forging pressure to produce a weld. The weld in the one side parallel gap process (Figure 3-8) used for joining solar cells is really a series weld in which the current streaks down through an electrode into the two pieces of material being welded and back through another.

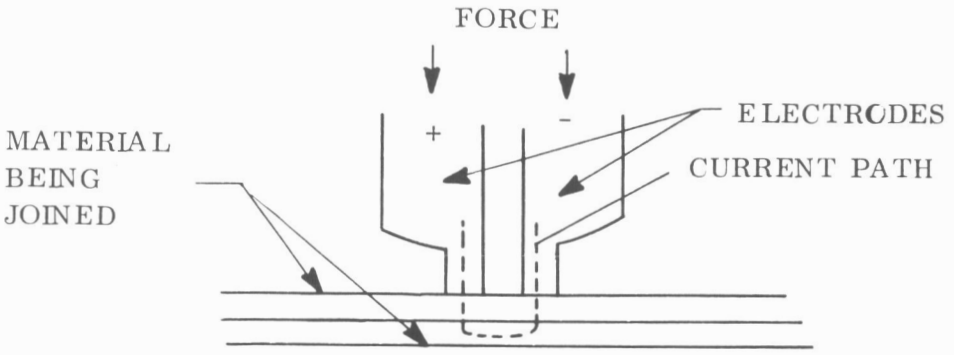


Figure 3-8. Parallel Gap Resistance Welding

3.1.2.3.2 Fabrication of a Welded Interconnection

The welds were produced on a Unibond Dual Sensing Circuit Flatpack Welder. First, the surfaces of the cell tabs to be joined were cleaned with ethyl alcohol and allowed to air dry for 10 to 15 minutes. Then, the cells were placed face to face and joined along part of the tab interface with GT100. With the negative cell contact on the bottom, the tabs to be joined were placed under the welding electrodes and two rows were made of 30 gap welds each.

Initially, the welder was set in its manual mode with the pulse width at 2 to 20 milliseconds. The other settings were:

Electrode gap:	15 mils
Amplitude control:	0
Modulation Control:	500
Force:	16 oz

The amplitude control was advanced in 0.05 volt increments and welding attempted until a good weld was produced (see Table 3-3).

Table 3-3. Selection of Optimum Weld Schedule

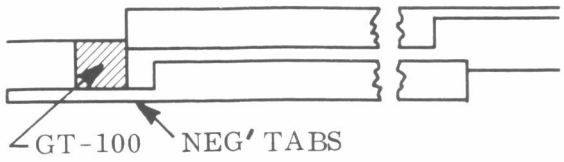
Sample No.	Amplitude (volts)	Remarks
1	0.5	No weld
	1.0	No weld
	1.05	Weld (weak)
	1.10	Weld (weak)
	1.15	Good Weld
	1.20	Good Weld - selected schedule
	1.30	Good Weld (Visable arcing)
2		Same as above
3		Same as above

The final weld schedule was:

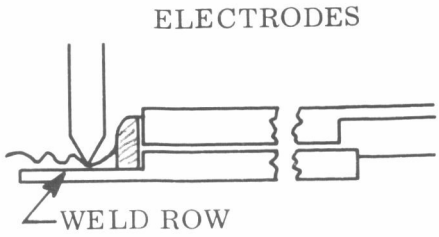
Pulse Width - 10 milliseconds
Electrode Gap - 0.015 inch
Amplitude - 1.20 volts
Forging Force - 16 ounces

The resistance of the welded interconnection was reasonably low; however, the mechanical strength of the unsupported welded contact was very low, thus the need for the GT100 reinforcement before welding.

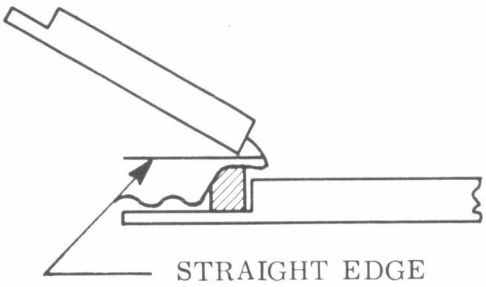
Following welding, the upper cell was folded back along the positve cell tab and the joint was the reinforced as for the soldering process. Figure 3-9 shows the joint fabrication sequence.



(a) INITIAL REINFORCEMENT

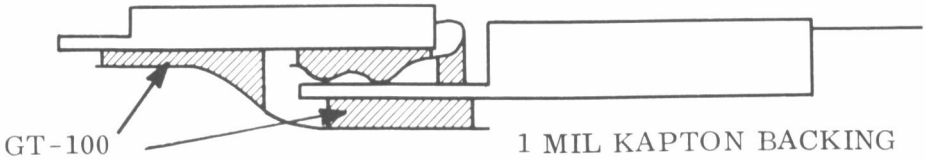


(b) WELDING



(c) TOP CELL BEING FOLDED

(d) ADDITION GT-100 REINFORCEMENT



(e) COMPLETED JOINT

Figure 3-9. Interconnection and Joint Fabrication by Parallel Gap Resistance Welding

Initial conductivity of the samples (No. 23 and 24 of Table 2-2) fabricated by the reinforced resistance welded technique was slightly less than that obtained with either the soldered or conductive bonded methods. This could probably be increased by the addition of another row of welds.

The ultimate tensile strength for the Butt Joint configuration was 19 pounds which closely correlates with the strength of the reinforced solder joints. This seems to indicate that the mechanical strength of both types of joint is almost completely dependent on the reinforcement design rather than on the method of electrical interconnection. A slow but definite degradation trend was evident in the first roll tests. However, the joints were still well within the resistivity goal limit after the four roll tests in sequence.

3.1.3 SERIES JOINING METHOD SELECTION FOR QUALIFICATION PROGRAM

The series joining methods were reviewed with a view toward selecting for qualification two methods having high mechanical strength, low resistance, manufacturability, and low weight. On the basis of tensile strength and roll tests, the reinforced soldered and welded butt joints were only slightly lower than their common substrate counterparts. The choice was therefore among the butt-joint methods since they were of comparable strength, lower in weight, and easier to fabricate than the common substrate methods. The choice narrowed further to the soldered joint (mechanically, the solder alone was stronger than the welded connection and therefore easier to handle) and the conductive epoxy bonded joint. Additionally, this choice offered essentially the same joint configuration formed by different methods using entirely different materials.

3.1.3.1 Primary Process for Series Connection

a. Obtain electrical interconnection between series cells by soldering with No. 235 Indium Bismuth solder in a strip 0.12 inch wide at the end of the positive tab. Provide mechanical reinforcement with a strip of GT100 thermoplastic adhesive cured in the layer directly between the positive and negative tabs between the soldered seam and the active cell. This operation is performed with the cells lying face to face.

b. Fold back the cell contributing the positive tab at the edge of the reinforcement and bond the folded positive tab to the back of the cell with GT100 thermoplastic adhesive.

c. Apply a 1 mil by 5/8 in. Kapton strip across the back of the joint and bond to the backs of the cells with GT100.

3.1.3.2 Back Up Process for Series Connection

a. Pre-fold the positive tabs 0.188 inch from the end of the gridwork.

b. With both cells lying face down apply conductive adhesive, SMRD 745 Flexible Epoxy loaded 50 percent by weight with Alcan Silver Flake, to both sides of the positive tab. The joint is covered by Teflon tape and cured for sixteen hours at 150^{O}F. The conductive epoxy bond provides both the electrical interconnection and mechanical joining.

3.2 PARALLEL INTERCONNECTION

3.2.1 CONDUCTIVITY

The function of the parallel connection in an array is one of fault protection and cell mismatch accommodation. Parallel connections at each series joint provide bypass paths through which the current in a row can move around a low output cell. To evaluate parallel joint resistance, it is necessary to simulate a fault condition and force the current to follow a diagonal path through a module. An unwanted effect of this procedure is to have the parallel direction resistance of the cell's tabs included in the interconnection resistance data. To determine the magnitude of this effect, a single cell was instrumented and measured for parallel direction conductivitiy with the following results.

a. The resistance of the positive tab (0.0005 inch thick gold plated copper) in the parallel direction is 6.34 milliohms.

b. The resistance of the negative tab (0.0002 inch thick coating of silver loaded Pyre ML plastic) in the parallel direction is 83.8 milliohms.

c. The combined resistance of the two tabs in the parallel direction is 5.89 milliohms.

There was no specified goal with respect to the parallel interconnection conductivity, but attaining a configuration with performance comparable to the series interconnection was adopted as a goal. Of the various paralleling methods evaluated, only the designs which utilized a large copper cross over tab approached this goal.

3.2.2 MECHANICAL STRENGTH, PARALLEL JOINT

3.2.2.1 Tab Connected, Inline Method

Roll testing was the principal screening test for the parallel joining methods, the rolling flexure conditions of that test proving the most damaging to the joints.

As specified in the contractual work statement, one of the first parallel interconnection methods evaluated was a "Tab Connected, Inline" design using a copper foil tab of similar weight and dimensions to the positive cell tab. Sample 27 was constructed by this method using the reinforced soldered joint process resulting from the series joint activity. While the conductivity was good, the unit failed very early in the first roll test. Figure 3-10 is representative of this sample. Data is shown in Table 3-4.

A second "Tab Connected, Inline" sample using flexible photoetched tabs similar to those used successfully in previous programs with silicon and CdTe cells was constructed and tested (Sample 29) but met with only limited success. It appeared that a successful version of this construction could have been attained with further modification of the tab anchorage foot, but, as tested, the design was unsuitable.

Success in maximizing both conductivity and mechanical strength resulted from use of a tab 0.188 inch wide by 3 inches long of Schjel Clad L5550.[1] This sample, No. 32, exhibited the best performance of any method from both electrical and mechanical stability standpoints (Table 3-4).

1. Schjel Clad L5550 is a laminate of copper foil and 0.005 In. thick Mylar. The copper was 1/2 oz. per ft^2 (0.00067 In. Thick). Schjel Clad is a product of the G.T. Schjeldahl Co.

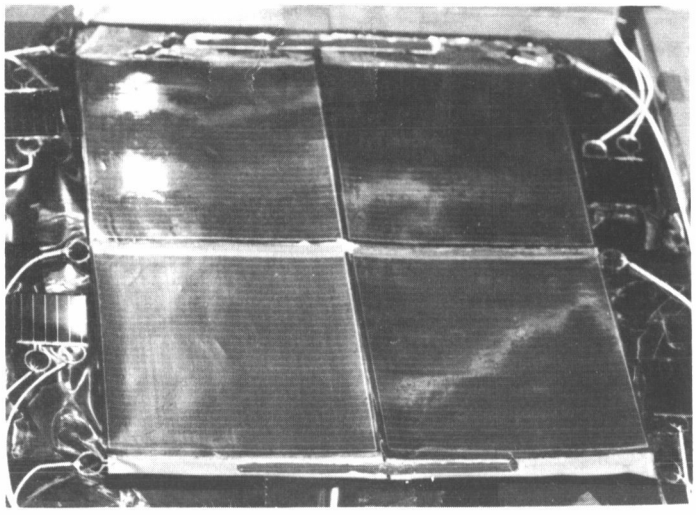


Figure 3-10. 2 Cell Parallel X 2 Cell Series Test Sample Using "Tab Connected, Inline Parallel Joining Method

3.2.2.2 Staggered Cell Parallel Joint

The staggered cell parallel joining method (Figure 3-11) was suggested by the Lewis Project Manager as a means of achieving the paralleling function through the use of the cell tabs and thus avoid adding additional thickness and weight to the joint. The initial amount of stagger evaluated was 1 cm, Samples 25 and 26. Figure 3-12 shows one such sample mounted on the roll tester in the parallel direction. This amount of stagger proved to be insufficient to either support the 5 pound tension load in the butt joint configuration or remain stable when used with the resistance welded joining method.

The step to full half cell staggering was made for Samples 28 and 31, (Figure 3-11). These modules differed only in the series joining method, 28 being soldered while No. 31 was joined by conductive epoxy bonding. Sample 28 was slightly more conductive than Sample 31 which is characteristic of the consistently higher conductivity of soldered interconnections compared to conductive epoxy interconnections (Table 3-4).

Table 3-4. Summary of Parallel Joint Performance - Primary and Secondary Roll Tests

Sample No., Type (All Modules of Clevite Plastic Substrate Cells)	Parallel Joint Resistance - Milliohms			Comment
	Initial	Post Prim. Roll Common Substrate	Post Prim. Roll Butt Joint	
25, 1 cm Stagger No. 235 In-Bi Solder GT100-Reinforced	13.42	14.20	"Failed"	1 cm joint could not support 5 pound tension load without substrate
26, 1 cm Stagger Resistance Weld GT-100 Reinforced	20.48	24.68	No Test	Resistance Welding Activity was stopped as performance was not competitive
27, Copper Foil Tab, Inline, (0.0005"x0.188" x3") No. 235 In-Bi Solder GT-100-Reinforced	6.40	"Failed"	----	Progressive degradation from start. Complete open of tab by 50 cycles.
28, Half Cell Stagger No. 235 In-Bi Solder GT100-Reinforced	22.72	23.56	Test Stop	Copper Tab at Sample Edge Failed with Resultant Buckling of Cell. Suitable Parallel Des
29, Photo Etched Tab, Inline, No. 235 In-Bi Solder GT-100 Reinforced	14.60	14.20-19.60	15.60-19.40	Eratic Resistance Indicates partial open in tab joint.
31, Half Cell Stagger SMRD745+50%Ag Cond. Epoxy	38.7	40.6	43.5	Suitable Candidate For Qualification
32, Schjel Clad Tab, Inline, (L5550, 0.188x3) No. 235 In-Bi Solder GT-100 Reinforced	7.08	7.30	7.58	Most Suitable Candidate For Qualification

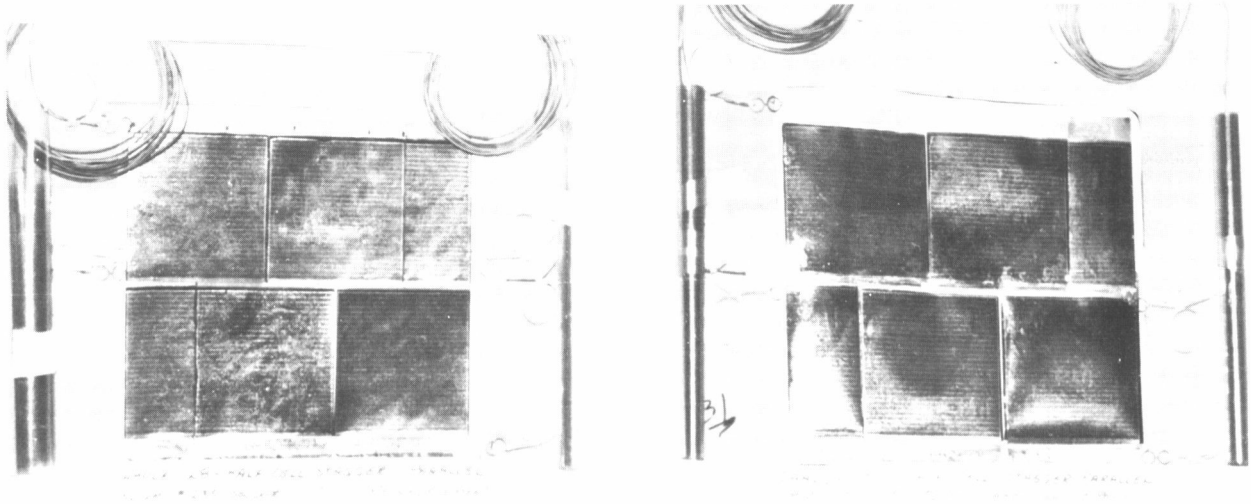


Figure 3-11. 2-1/2 Cell Parallel X 2 Cell Series Test Sample Using "Half Cell Staggered" Parallel Joining Method

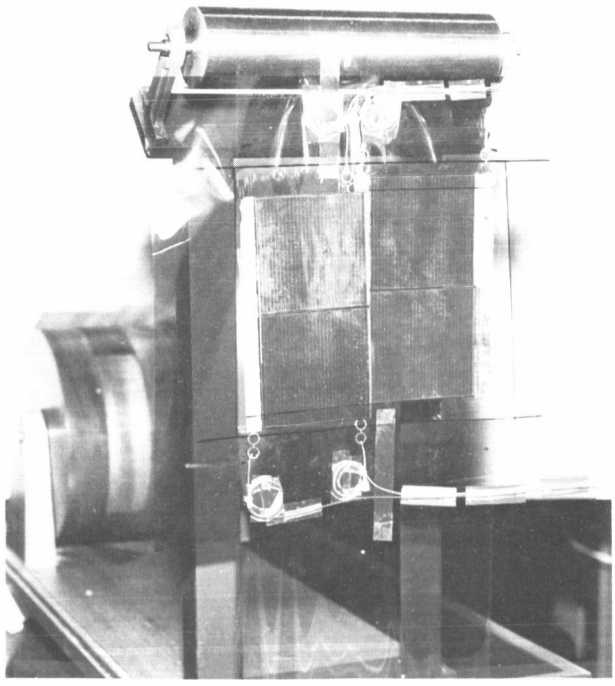


Figure 3-12. 1 Centimeter Staggered "Test Module Sample on Roll Tester

3.2.3 PARALLEL INTERCONNECTION METHOD SELECTION FOR QUALIFICATION PROGRAM

Selection of the methods for parallel interconnection was made primarily on the basis of conductivity and secondarily on the basis of mechanical strength. The primary method, Schjel Clad Tab Inline, was used on both soldered and conductive bonded test samples while the back-up method, Half Cell Staggered, was used only on soldered test samples.

3.2.3.1 Primary Process for Parallel Interconnection

The positive tabs of two cells already connected in series, but not folded back are interconnected by a 3-inch by 3/16-inch tab of Schjel Clad L5550 by soldering with Indium No. 235 solder or by conductive adhesive bonding. The back fold mechanical joint is then obtained by bonding with GT100 for the soldered joint or with the same conductive epoxy adhesive for the bonded joint. A 5/8-inch wide strip of 0.001 Kapton is then bonded along the joint to provide strength in the parallel direction (applicable only to soldered configuration). Also, a 3/8-inch strip of 0.001 mil Kapton and GT100 bridging the edges of the cells to more nearly attain the general properties of a uniform sheet is used.

3.2.3.2 Secondary Process for Parallel Interconnection

Staggering the cells by half the width and using either the soldering or conductive epoxy process of the series joining methods yields the staggered cell parallel interconnection.

SECTION 4

QUALIFICATION PROGRAM FOR CdS SOLAR CELL INTERCONNECTION METHODS

4.1 DESCRIPTION OF QUALIFICATION TESTS AND TEST SAMPLES

Testing in accordance with the Work Statement (Contract NAS3 10605) was performed to demonstrate that the candidate CdS interconnections are qualified to meet customer requirements. Three categories of tests were performed, Ultimate Tensile, Specialized Dynamic (Primary and Secondary Roll Tests), and Vacuum Thermal Cycling and High Temperature Dwell. Loading directions for the mechanical tension loads were varied as specified and included both series and parallel directions for all types of tests.

Test samples for the Roll and Tensile tests were constructed of Class III cells (mechanical samples having no electrical performance specification), while customer Class I operating cells were used for the thermal vacuum test samples. As in the experimental evaluation program, interconnection resistance was monitored during the tensile and roll tests by means of instrumentation assembled in accordance with Figure 3-1. Solar cell performance under illuminated conditions was monitored during the Vacuum Thermal Cycling and Dwell tests.

The number and types of test sample configurations to be evaluated during the qualification testing program was established through joint agreement between the Lewis Project Manager and the GE Technical Leader. These are indexed and shown schematically in Figure 4-1. Twenty one test samples were fabricated and tested under this segment of the program. The mechanical and electrical joining methods are shown in Figure 4-2.

Series resistance in the interconnections was monitored by instrumentation set up to detect the voltage drop in the interconnection due to a regulated current. Accuracy of the data was affected by the presence of a parallel direction current flow and corresponding voltage drop within the interconnection which could either add to or subtract from the series voltage drop signal. Variations in the current path from cell to cell were caused by two conditions,

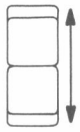
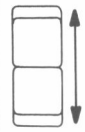
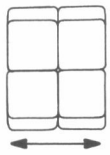
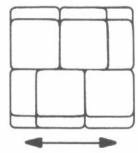
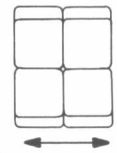
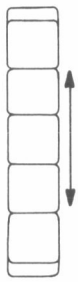
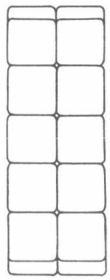
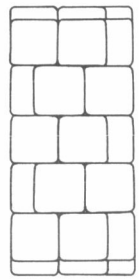
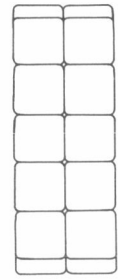
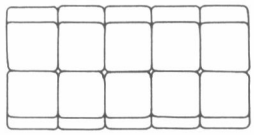
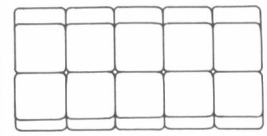
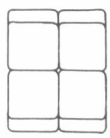
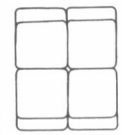
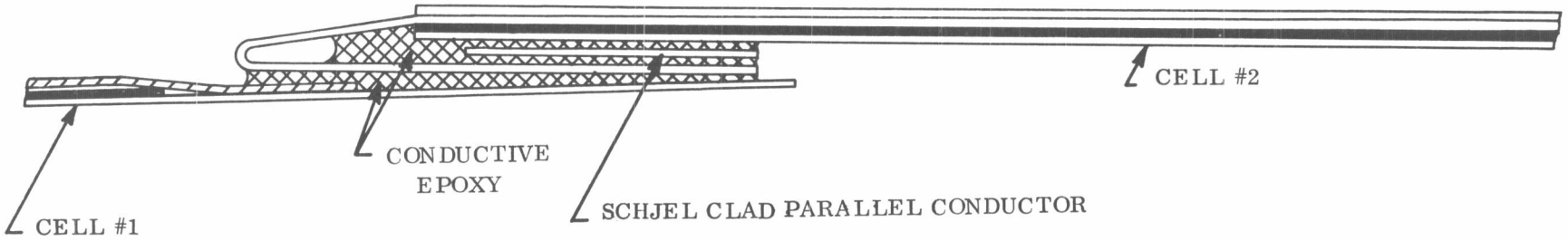
JOINING METHOD	INDIUM SOLDER - GT 100 REINFORCED		CONDUCTIVE EPOXY
PARALLEL METHOD	SINGLE ROW OR "SCHJEL CLAD TAB"	"STAGGERED CELLS"	SINGLE ROW OR "SCHJEL CLAD TAB"
ULTIMATE TENSILE SERIES DIRECTION	 1 PAR X 2 SERIES SAMPLE NO. 35 1 PAR X 2 SERIES SAMPLE NO. 36	—	 1 PAR X 2 SERIES SAMPLE NO. 46
ULTIMATE TENSILE PARALLEL DIRECTION	 2 PAR X 2 SERIES SAMPLE NO. 32 2 PAR X 2 SERIES SAMPLE NO. 48	 2 1/2 PAR X 2 SERIES SAMPLE NO. 28	 2 PAR X 2 SERIES SAMPLE NO. 49
PRIMARY ROLL TEST 100 CYCLES CELLS FACING OUTWARD OVER 2 INCH ROLLER, 5 LB TENSION LOAD, SERIES	 1 PAR X 5 SERIES SAMPLE NO. 38 1 PAR X 5 SERIES SAMPLE NO. 55	—	1 PAR x 5 SERIES SAMPLE NO. 40 1 PAR X 5 SERIES SAMPLE NO. 41
PRIMARY AND SECONDARY ROLL TEST 100 CYCLES FACING OUTWARD AND 100 CYCLES FACING INWARD OVER 2 INCH ROLLER, 5 LB TENSION LOAD, SERIES	 2 PAR X 5 SERIES SAMPLE NO. 43 2 PAR X 5 SERIES SAMPLE NO. 44	 2 1/2 PAR X 5 SERIES SAMPLE NO. 42 2 1/2 PAR X 5 SERIES SAMPLE NO. 47	 2 PAR X 5 SERIES SAMPLE NO. 51
PRIMARY ROLL TEST 100 CYCLES CELLS FACING OUTWARD OVER 2 INCH ROLLER, 5 LB TENSION LOAD, PARALLEL DIRECTION	5 PAR X 2 SERIES SAMPLE NO. 53 5 PAR X 2 SERIES SAMPLE NO. 54 	—	5 PAR X 2 SERIES SAMPLE NO. 52 
THERMAL CYCLING 24 CYCLES BETWEEN 55°C AND -70°C WITH 5 LB BIAXIAL, 5 LB SERIES, AND 5 LB PARALLEL LOADING	 2 PAR X 2 SERIES SAMPLE NO. 45		 2 PAR X 2 SERIES SAMPLE NO. 50

Figure 4-1. Summary Index of Qualification and Test Sample Configurations



CONDUCTIVE EPOXY BONDING METHOD WITH TAB INLINE PARALLELING

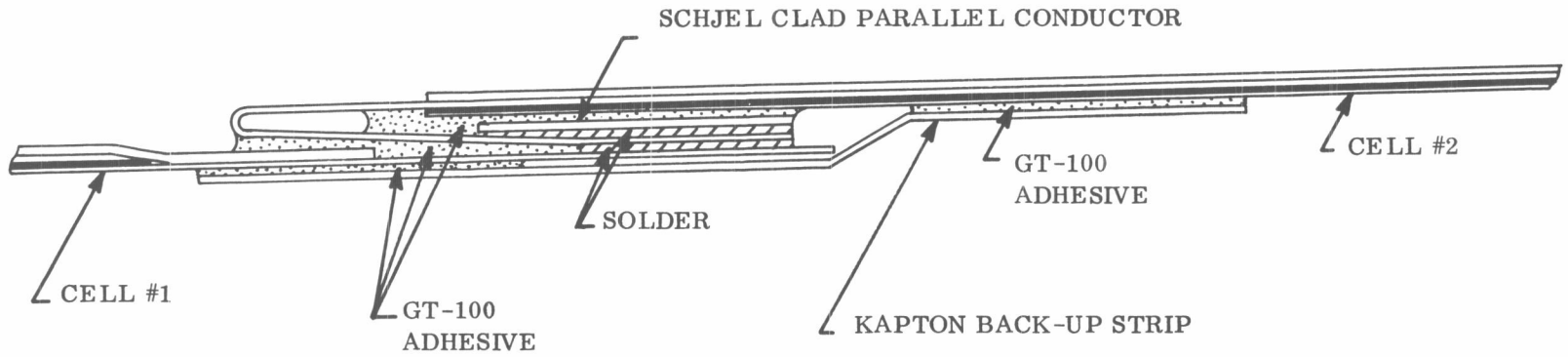


Figure 4-2. Reinforced Soldered and Conductive Epoxy Bonded Joints

(1) the diagonal path resulting from the use of opposite corners for the regulated power supply current, and (2) the nonuniform sheet diode properties of the cells. The diagonal current path effect was of a polarity which subtracted from the joint resistance voltage signal. In cases of high conductivity series interconnections, the parallel current effect voltage drop sometimes exceeded the series drop resulting in negative "observed" resistances.

The sheet diode variations were random and of both positive and negative polarity with respect to the series signal. While the individual effect on the data for a single interconnection was dominant at times, the overall influence for a long sample averaged toward zero since a positive shift at one joint tended to be offset by a similar magnitude negative shift at the succeeding joint.

Data reduction to ascertain the highest accuracy resulted in an approach which minimized the sheet diode effect by using the algebraic average of the observed points for a sample, and which compensated for the diagonal current path effect directly by adding to the observed points the proportionate share of the diagonal path voltage drop attributable to an individual cell. The basis for this compensation was the resistance of the two cell tabs in parallel in the parallel direction, 5.89 milliohms. This value is dominated by the resistance of the photoetched positive tab-grid, the most reproducible element of the cell. Data will be presented "as observed" and will be accompanied by a "compensated" value which incorporates the diagonal effect correction.

4.1.1 ULTIMATE TENSILE TEST

Ultimate Tensile Test samples were mounted in the fixture shown in Figure 4-3 and loaded incrementally (normally 2 pounds per step) by addition of the weights to the cable suspended tray (Figure 3-4). Elongation over a 2-inch span was monitored by a dial indicator with readings taken to the nearest 0.0001 inch. All series joints in the sample were monitored for conductivity at each load setting.

Ultimate Tensile data were obtained for single joint speciments specifically constructed as "Ultimate Tensile" specimens. Both series and parallel joints were tested in this manner

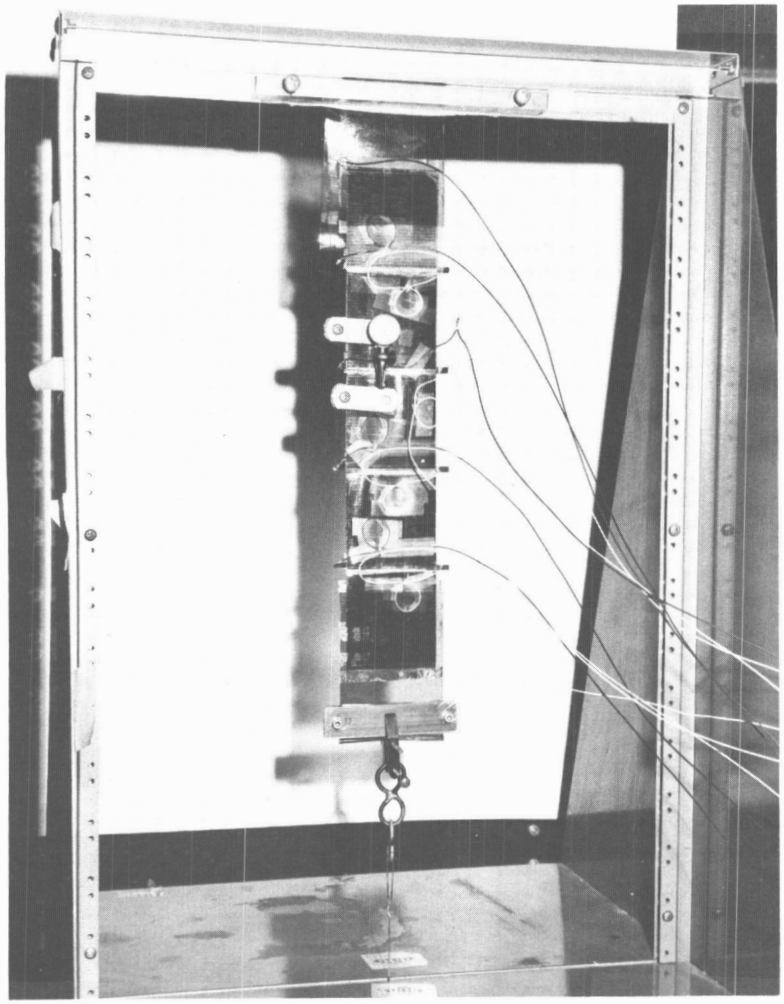


Figure 4-3. Sample 55 Mounted in Tensile Test Fixture

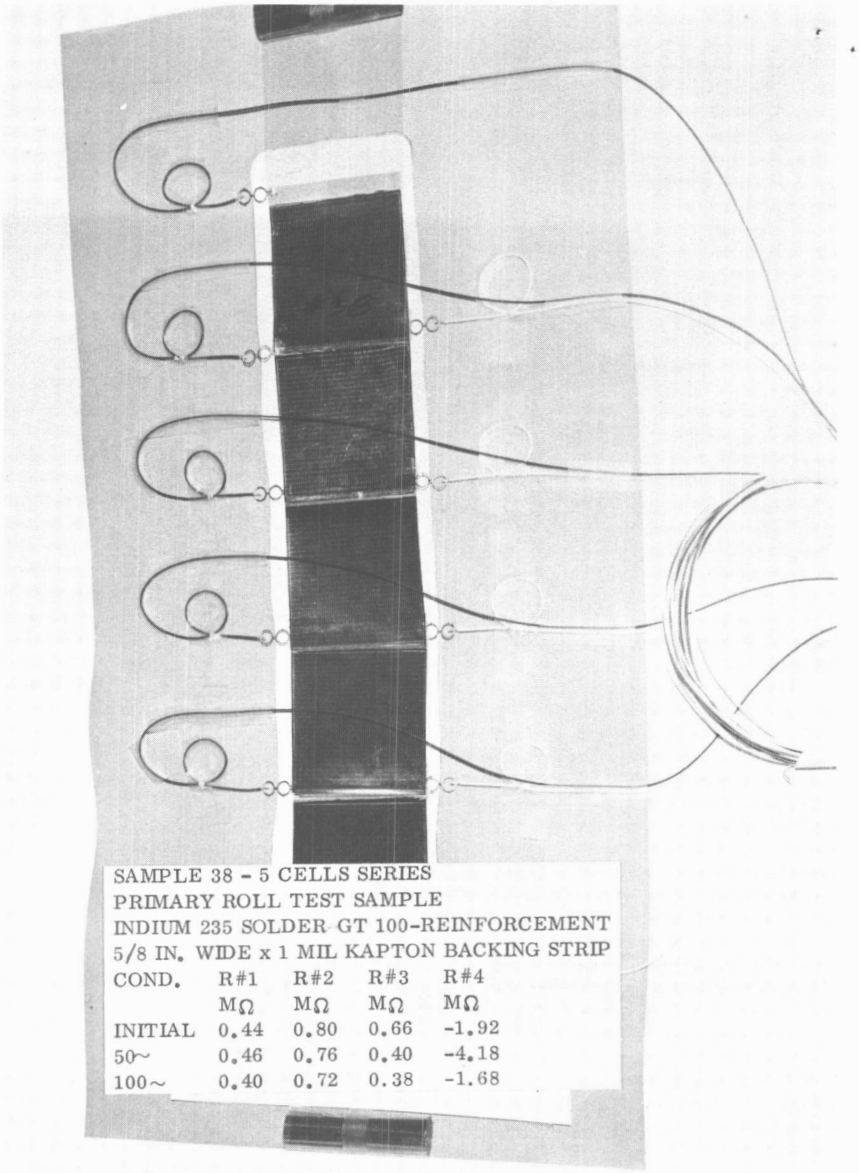


Figure 4-4. Sample 38, 1 Parallel x 5 Series, Roll Test Sample Showing Separate Sheet Support of the Instrumentation Wiring

to obtain a "maximum strength limit" on specimens which had not been stressed in any other test. In addition, data were taken on multijoint specimens after they had completed the roll testing sequences for which they were originally constructed.

4.1.2 ROLL TEST

The roll test fixture used during the qualification testing program is the same as that used for the experimental program (Paragraph 3.1.2). One feature, the method of mounting the instrumentation wiring, was altered for most of the qualification samples. For the experimental program and the initial qualification samples, the wiring was supported by a separate Kapton sheet and was connected to the test sample through use of photoetched flexible tabs (Figure 4-4). To accommodate the wider qualification test samples on the roller, since they required most of the area used by the separate support sheet, the mounting method was changed so that the sample itself supported the wires (Figure 4-5). The joint was still protected from feeling the wire flexing strains by means of the photoetched or Schjel Clad tab.

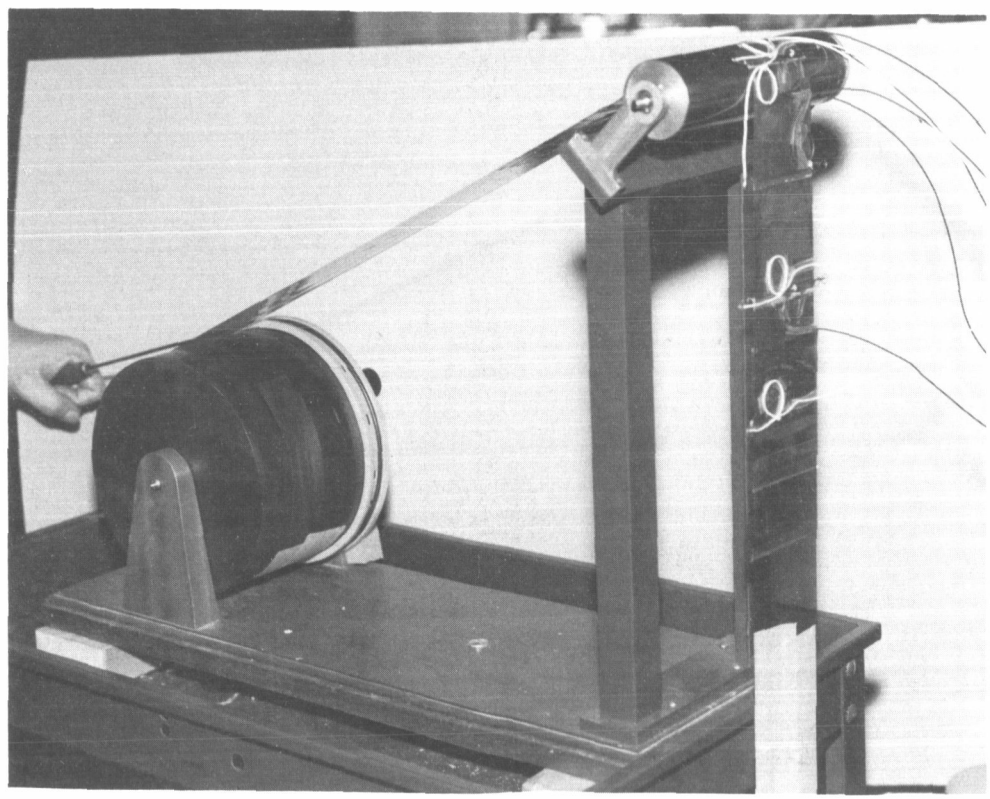


Figure 4-5. Sample 41, 1 Parallel x 5 Series, Roll Test Sample, Showing Test Sample Support of Instrumentation Wiring

4.1.3 VACUUM THERMAL CYCLING AND HIGH TEMPERATURE DWELL TEST

Performance of the CdS solar cell interconnections in a simulated application was obtained by subjecting two samples to the Vacuum Thermal Cycling and High Temperature Dwell Test. The samples were assembled with customer supplied Class I cells. Sample 45 was constructed using the reinforced soldered method and sample 50 was of bonded construction. The testing sequence was one of twenty-four thermal cycles between -70°C and +55°C followed by an 8-hour period at operating temperature (approximately 55°C). Thermal loading, both heating and cooling, was by radiation. Heating was accomplished by illumination from a carbon arc (Figures 4-6 and 4-7). The light beam was reflected through a port in the top cover of the vacuum chamber (Figure 4-8) and passed through the liquid nitrogen cooled cylinder inside the chamber (Figure 4-9) Finally striking the test module mounted at the base of the cylinder (Figure 3-10). Cooling was accomplished by radiation to the LN_2 cooled walls with the light shut off.

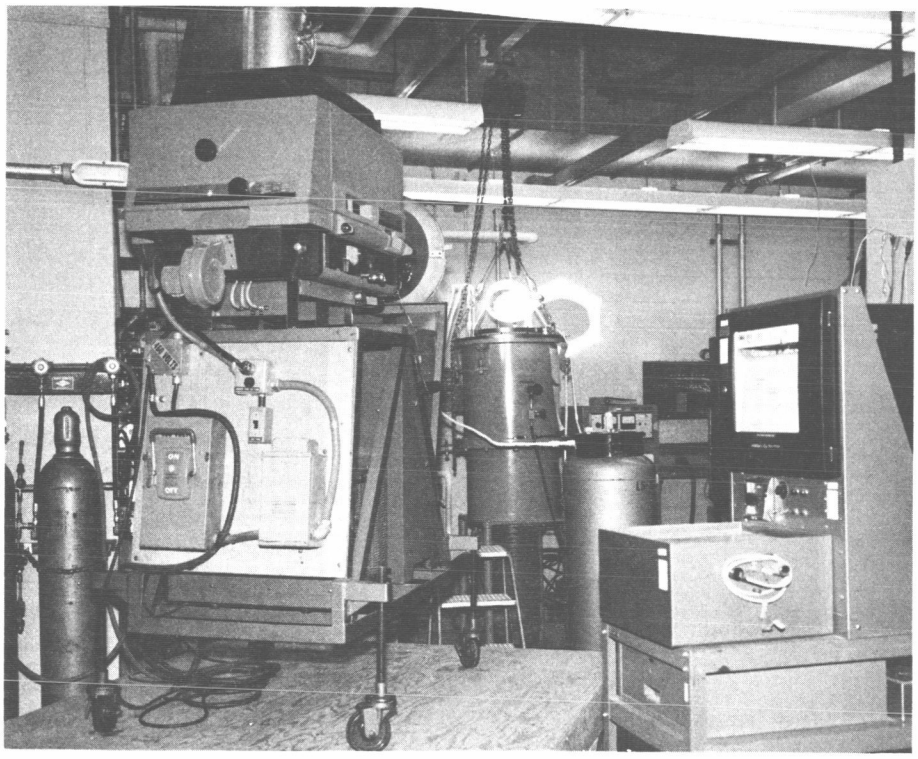


Figure 4-6. Solar Simulator-Vacuum Chamber Test Installation for Thermal Cycling Test of CdS Solar Cell Modules

Figure 4-7. Carbon Arc Solar Illumination Source of CdS Solar Cell Tests

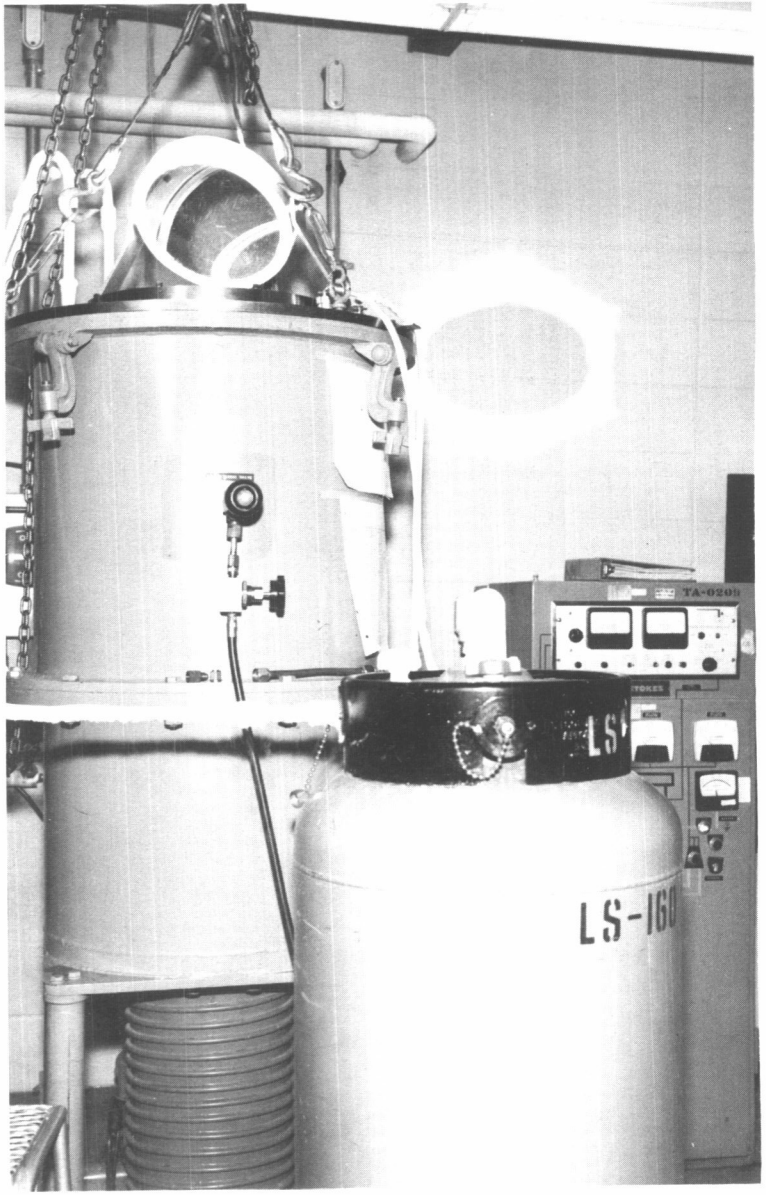


Figure 4-8. Thermal Cycling Vacuum Chamber with Top-Mounted Mirror and Liquid Nitrogen Supply for Cold Walls

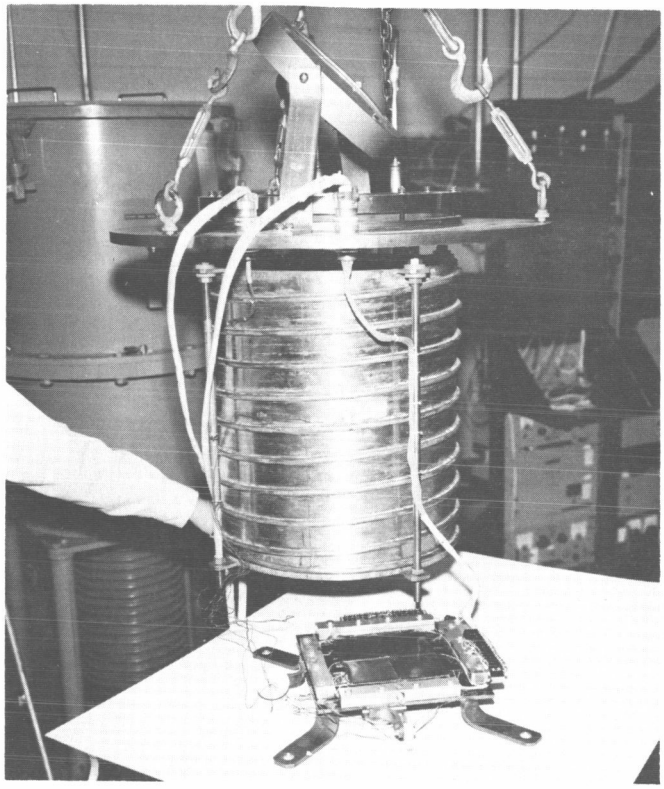


Figure 4-9. Vacuum Chamber with Thermal Cycling Test Equipment Mounted (Beam Deflection Mirror, LN, Cooled Cylinder, Test Plane Mount)

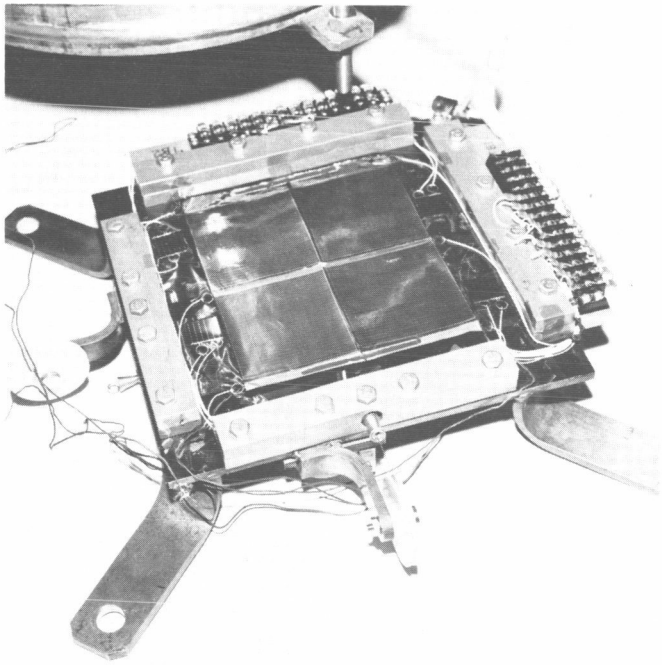


Figure 4-10. Sample 50 Mounted on Test Plane Fixture with 5 Pound Tension Load in Series Direction

Mechanical loading of the joints of 5 pounds in either or both directions was possible through the use of Neg'ator springs. The drive cable of the Neg'ator passed over a pulley and attached to the free substrate clamp bar. This loading simulated an extreme tension load. Interconnection resistance measurements were taken at several temperatures during each cycle. Voltage-Current curves were taken at the start of the test and after each group of six cycles. Following the cycling portion of the test, the sample dwelled at operating temperature for eight hours. This dwell operation was included to observe electrical performance stability of the sample since tests on other customer programs had indicated a performance variation under similar conditions.

Sample 45 (soldered) was subjected to the 24 cycle-hour dwell sequence three times; once with 5 pound loading in both the series and parallel axes, once with the 5 pound load in only the series axis, and once with the 5 pound load in the parallel direction.

Sample 50 (bonded) was tested once, with the 5 pound loading in the series direction only, the normal case for the projected application.

4.2 SUMMARY OF QUALIFICATION TEST RESULTS

4.2.1 ULTIMATE TENSILE TEST RESULTS OF SERIES JOINTS

Ultimate Tensile Tests were performed in the series axis direction on nine qualification program samples. A comparison of these results standardized to a common basis of a series string one cell wide is shown in Figure 4-11. Two comparative trends are evident, (1) that the conductive epoxy bond is stronger than the reinforced solder joint both new (55 pounds versus 46 pounds average) and after roll test flexure (57 pounds versus 28.6 pounds average), and (2) that the ultimate tensile strength of the reinforced solder joint is degraded by the flexure cycling imposed by the roll tests (46 pounds new average versus 28.6 pounds post roll test average) while the conductive epoxy bonded joint is unaffected by the flexural cycling (55 pounds initially for No. 46 versus 57 pounds of the post roll test for No. 40). The 43.5 pound post roll test value for conductive epoxy sample No. 51 is not included in the above comparisons because the test was stopped with a total load of 87 pounds

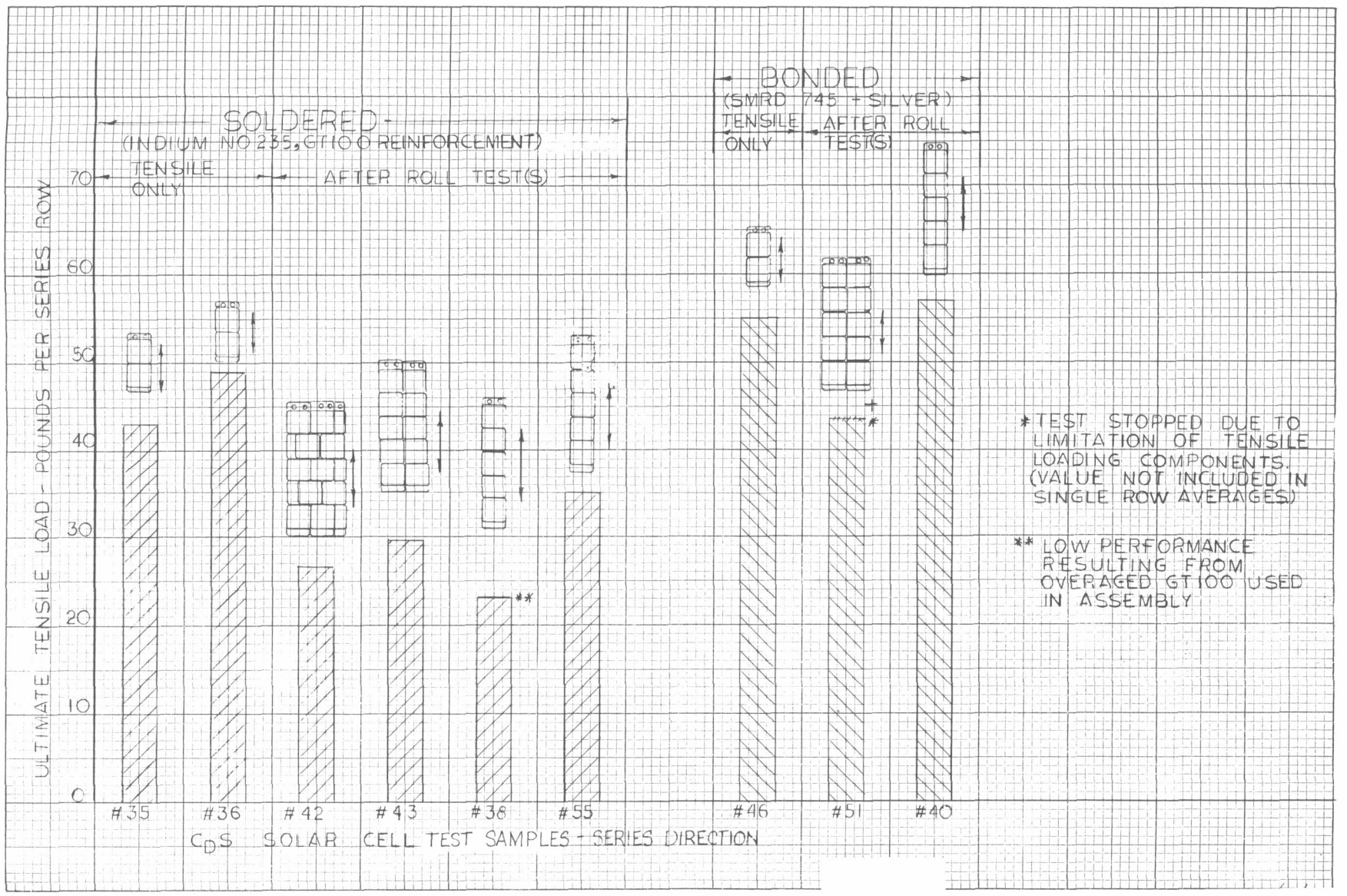


Figure 4-11. CdS Solar Cell Series Direction Ultimate Tensile Test Standardized Data Comparison

on the specimen at which point the equipment strength stopped the test rather than a deficiency in the sample performance.

4.2.2 ULTIMATE TENSILE TESTS OF PARALLEL JOINTS

Ultimate Tensile tests in the parallel direction were run on seven qualification test samples. All samples were two rows of cells in series, and varied in the number of cells in parallel as well as the method of construction. As with the series direction tests the performance pattern enables some comparative evaluation to be performed (Figure 4-12). Immediately evident is the general level difference between the reinforced soldered and bonded samples, with the soldered samples being the stronger (54.7 pounds average for the 2 row soldered samples versus 35 pounds average for the 2 row bonded samples). This is the reverse of the relative merit observed on the series samples and is more attributable to the backing seam tape of 1 mil Kapton, used only with the soldered joints, than to the joining process. This backing tape directly supports loading in the parallel direction.

A second comparison, that of the "tensile only" samples with those tested "after roll test flexure cycling" shows the flexed samples to perform nearly the same or better than the "tensile only" samples, indicating that the roll testing did not produce measurable degradation, as it did in the soldered samples of the series direction test.

When referenced against the tensile loading requirements for a roll-up solar array implied by the 2.5 pound/cell tension requirements of the roll and vacuum thermal tests, all of the tensile strength results are adequate by a wide margin. Of most importance is the series direction strength since it is the normal direction of loading.

4.2.3 PRIMARY AND SECONDARY ROLL TESTS OF SERIES JOINTS

Simulation of the combined tension and flexure loading of a roll-up solar array blanket was provided by the roll tests. The variously configured samples were cycled back and forth over a 2 inch diameter roller at velocities of 1 ft/sec (nominally) for 100 cycles. Tests with the active side of the cell away from the roller were termed "Primary" while tests with the active side of the cell against the roller were termed "Secondary."

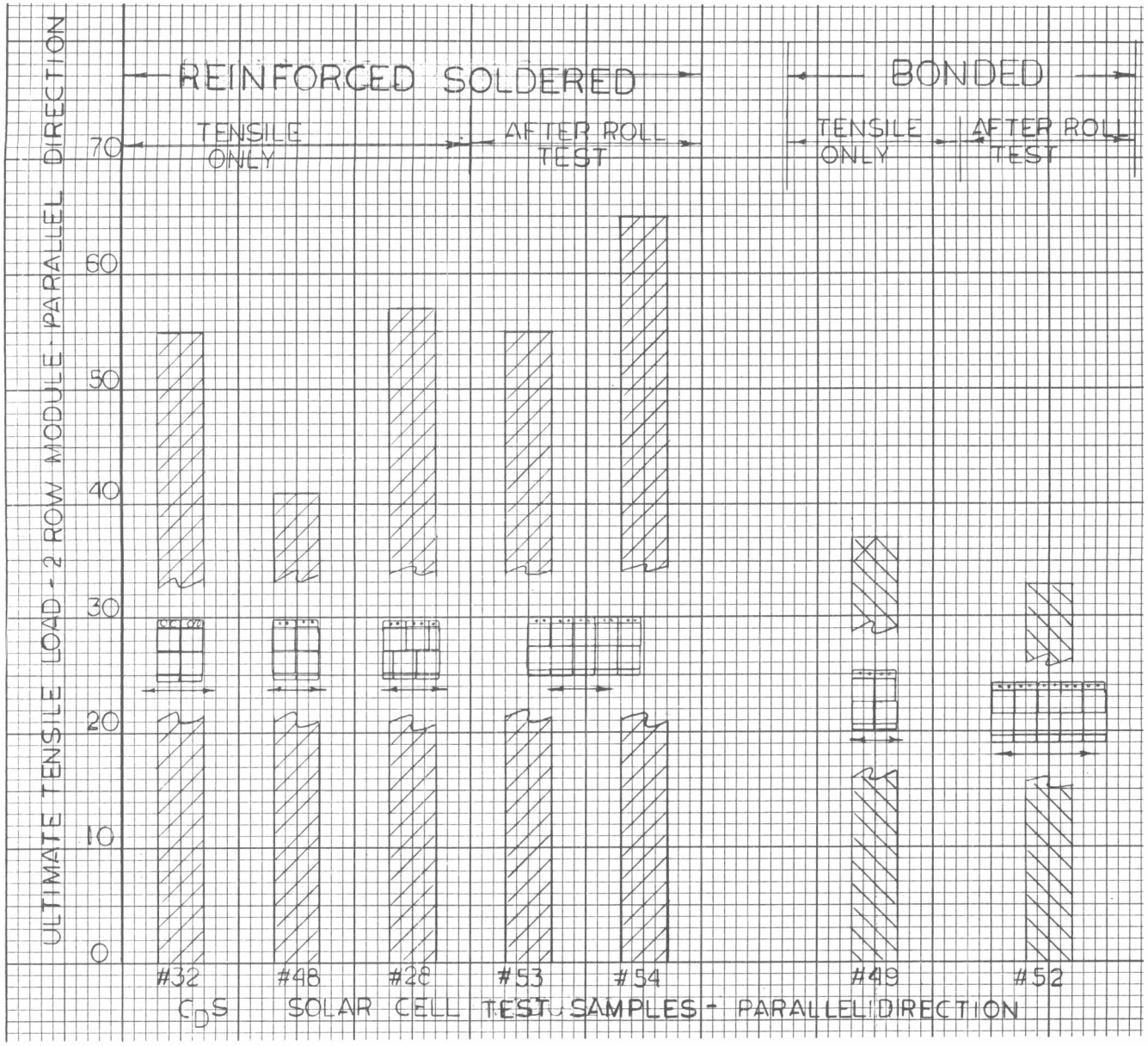


Figure 4-12. CdS Solar Cell Parallel Direction Ultimate Tensile Test Data Comparison

Roll test samples were five cells in series and either single row, double row, or staggered parallel configurations. The voltage drop of each of the four interconnections was monitored continuously during flexural cycling.

Individual readings are affected by both the diagonal current path effect and the variable sheet diode properties of the cells which can either add or subtract voltage to the series voltage drop. A straightforward compensation for the diagonal current path effect based on the parallel direction resistances of the positive and negative tabs was derived and has been applied to the observed data. The more erratic property, the sheet diode variability, averages toward zero over the length of the module, and while its effect on individual points can be dominatingly large, its effect virtually disappears when taking the algebraic average of the data points for a long sample. Comparative evaluation of interconnection resistance values and joint stability is based on the averaged compensated results.

Detailed before-and-after roll test data is shown in Figure 4-13 for the roll test samples. The comparison of the averaged compensated values is shown in Table 4-1. Stability of the interconnections of all types is evident since changes of less than one milliohm were the rule. Both the soldered and conductive epoxy inline method had lower average resistance values than the staggered soldered method.

Pre-roll test and post-roll test data for sample 47 show sizable polarity reversals in the observed data for joints 2 and 3. These values are greater than similar results with the inline methods due to the generally higher resistance level in the parallel direction for the "Staggered" interconnection and consequently form a good set of data to fit against an analytical model of the variable sheet diode effect. Figure 4-14 shows this analytical model graphically where the centerline of the current path is located by the parallel direction voltage drop established by subtracting out the average series resistance drop from each piece of observed data.

The model is a good fit for the condition of a shift in the current path caused by a change in the sheet diode characteristic of the cells in Row 3. The degree of mismatch in the paths

Table 4-1. Interconnection Resistivity and Stability Data

CdS Solar Cell Roll Test Samples - (Averaged, Compensated* Data)

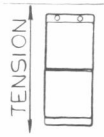
Sample No., Type	Ave. Interconnection Resistance-Milliohms Initial	Post Roll Test(s)	Change	No. of Cycles
Inline Soldered Methods				
No. 38 (1px5s)	1.175	1.135	-0.04	100
No. 55 (1px5s)	1.905	2.255	+0.35	100
No. 43 (2px5s)	2.40	2.45	+0.05	200
No. 44 (2px5s)	1.57	1.49	-0.08	200
Staggered Soldered Method				
No. 42 (2 1/2px5s)	3.90	3.34	-0.56	200
No. 47 (2 1/2px5s)	6.88	5.81	-1.07	200
Inline Conductive Epoxy Bonded				
No. 40 (1px5s)	1.43	1.55	+0.12	100
No. 41 (1px5s)	1.82	1.86	+0.04	100
No. 51 (1px5s)	2.30	2.85	0.55	200

*Compensation Values, Based on Parallel Resistance of Positive and Negative Tabs

Single Row Samples - +1.18 milliohms added to observed value
Double Row Samples - +2.36 milliohms added to observed value
2 1/2 Row Staggered Samples - +2.94 milliohms added to observed value

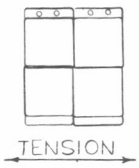
NO. 235 INDIUM SOLDER REINFORCED WITH KAPTON & GT 100 TH

SCHJEL CLAD L5550 TAB PARALLEL METHOD

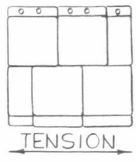


SAMPLE NO.	ULTIMATE LOAD-LBS	INTERCONNECTION RESISTANCE, MILLIOHMS			
		OBSERVED		COMPENSATED	
		INITIAL	MAX LOAD	INITIAL	MAX LOAD
35	43	-0.30	-0.24	2.64	2.70
36	49	0.42	0.70	3.36	3.64

STAGGERED CELL PA

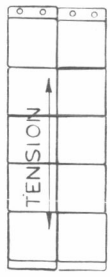


SAMPLE NO	ULTIMATE LOAD-LBS	COMBINED PARALLEL AND SERIES JOINT RESISTANCE, MILLIOHMS	
		OBS, INITIAL	OBS, MAX. LOAD
32	55	7.38	7.74
48	41	3.22	3.08

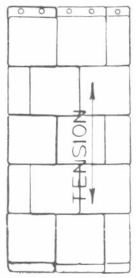


SAMPLE NO	ULTIMAT LOAD-LB
28	57

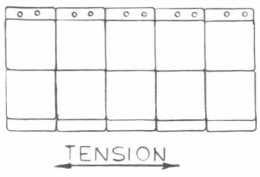
SAMPLE NO	ULTIMATE TENSILE LOAD-LBS	RESISTANCE MILLIOHMS			
		OBSERVED		COMPENSATED	
		INITIAL	AFTER 100 CYCL'S	INITIAL	AFTER 100 CYCLES
38	23	1) 0.44	0.40	1.62	1.58
		2) 0.80	0.72	1.98	1.90
		3) 0.66	0.38	1.84	1.56
		4) -1.92	-1.68	-0.74	-0.50
	(AVG)	-0.005	-0.045	1.175	1.135
55	35	1) 0.74	0.96	1.92	2.14
		2) 1.78	1.20	2.96	2.38
		3) 0.18	0.14	1.36	1.32
		4) 1.82	2.00	3.00	3.18
	(AVG)	1.130	1.075	1.905	2.255



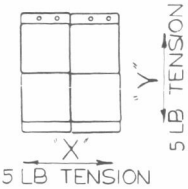
SAMPLE NO	ULTIMATE TENSILE LOAD-LBS	RESISTANCE MILLIOHMS			
		OBSERVED		COMPENSATED	
		INITIAL	AFTER 200 CYCLES	INITIAL	AFTER 200 CYCLES
43	59	1) 2.76	3.30	5.12	5.66
		2) -4.32	-4.50	-1.96	-2.14
		3) -0.54	-0.38	1.82	1.98
		4) 2.28	1.96	4.64	4.32
	(AVG)	0.04	0.09	2.40	2.45
44	NOT TESTED	1) -0.78	-0.70	1.58	1.66
		2) -0.90	-1.30	1.46	1.06
		3) -1.90	-1.66	0.46	0.70
		4) 0.42	0.17	2.78	2.53
	(AVG)	-0.79	-0.87	1.57	1.49



SAMPLE NO	ULTIMATE TENSILE LOAD-LBS	O
		IN
42	67+	1)
		2)
		3)
		4)
	(AVG)	
47	NOT TESTED	1)
		2)
		3)
		4)
	(AVG)	



SAMPLE NO	ULTIMATE TENSILE LOAD-LBS	COMBINED PARALLEL + SERIES RESISTANCE, MILLIOHMS	
		OBS, INITIAL	OBS. AFTER 100 Cy
53	55	3.56	7.50
54	65	6.80	0.44



SAMPLE NO	THERMAL VACUUM TESTS
45	24 CYCLES -70°C ↔ 55°C, X AND Y LOADING
	8 HOURS 55°C, X AND Y LOADING
	24 CYCLES -70°C ↔ 55°C, Y LOADING
	8 HOURS 55°C, Y LOADING
	24 CYCLES -70°C ↔ 55°C, X LOADING
	8 HOURS 55°C, X LOADING

FOLDOUT FRAME 1

HERMOPLASTIC METHOD

RRELLEL METHOD

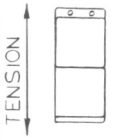
S	COMBINED PARALLEL AND SERIES RESISTANCE, MILLIOHMS	
	OBS, INITIAL	OBS, MAX LOAD
	39.1	42.0

BSERVED		COMPENSATED	
ITIAL	AFTER 200 CYCLES	INITIAL	AFTER 200 CYCLES
8.72	9.00	11.66	11.94
-17.76	-19.80	-14.82	-16.86
-1.80	- 2.88	1.14	0.06
14.68	15.28	17.62	18.22
0.96	0.40	3.90	3.34
11.20	11.28	14.14	14.22
9.84	-1.28	12.78	1.66
-0.59	8.02	2.35	10.96
-4.70	- 6.52	- 1.76	- 3.58
3.94	2.88	6.88	5.81

SMRD 745 + SILVER COND. EPOXY

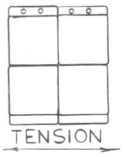
SCHJEL CLAD L5550 TAB PARALLEL METHOD

ULTIMATE



SAMPLE NO.	ULTIMATE LOAD - LBS	RESISTANCE, MILLIOHMS			
		OBSERVED		COMPENSATED	
		INITIAL	MAX LOAD	INITIAL	MAX LOAD
46	55	1.46	1.50	4.40	4.44

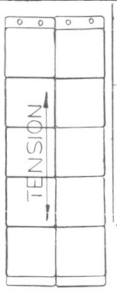
TENSILE



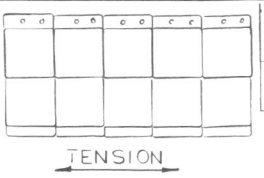
SAMPLE NO	ULTIMATE LOAD - LBS	COMBINED PARALLEL AND SERIES RESISTANCE, MILLIOHMS	
		OBS, INITIAL	OBS, MAX LOAD
49	37	1.20	2.48

ROLL TESTS

SAMPLE NO	ULTIMATE TENSILE LOAD - LBS	RESISTANCE MILLIOHMS			
		OBSERVED		COMPENSATED	
		INITIAL	AFTER 100 CYCLES	INITIAL	AFTER 100 CYCLES
40	57	1) 0.14	0.22	1.32	1.40
		2) 0.02	0.04	1.20	1.22
		3) -0.10	0.04	1.08	1.22
		4) 0.94	1.18	2.12	2.36
	(AVG)	0.25	0.37	1.43	1.55
41	NOT TESTED	1) - 1.08	-1.10	0.10	0.08
		2) 1.86	1.84	3.04	3.02
		3) 0.80	0.90	1.98	2.08
		4) 1.00	1.08	2.18	2.26
	(AVG)	0.66	0.68	1.82	1.86

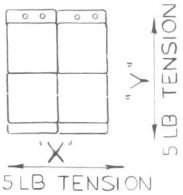


SAMPLE NO.	ULTIMATE TENSILE LOAD - LBS	RESISTANCE MILLIOHMS			
		OBSERVED		COMPENSATED	
		INITIAL	AFTER 200 CYCLES	INITIAL	AFTER 200 CYCLES
51	87+	1) 1.12	4.48	3.48	6.84
		2) -2.64	0.40	-0.28	2.76
		3) 5.32	1.06	7.68	3.42
		4) - 4.04	-3.96	-1.68	- 1.60
	(AVG)	- 0.06	0.49	2.30	2.85



SAMPLE NO	ULTIMATE TENSILE LOAD - LBS	COMBINED PARALLEL + SERIES RESISTANCE, MILLIOHMS	
		OBS. INITIAL	OBS AFTER 100 CY
52	33	- 4.53	- 4.49

VAC THERM. CYCLE



SAMPLE NO	THERMAL VACUUM TESTS
50	24 CYCLES -70°C ↔ 55°C, Y LOADING
	8 HOURS 55°C, Y LOADING

Figure 4-13. Data Summary - Qualification Test Program Samples

FOLDOUT FRAME

FOLDOUT FRAME 2

4-17/18

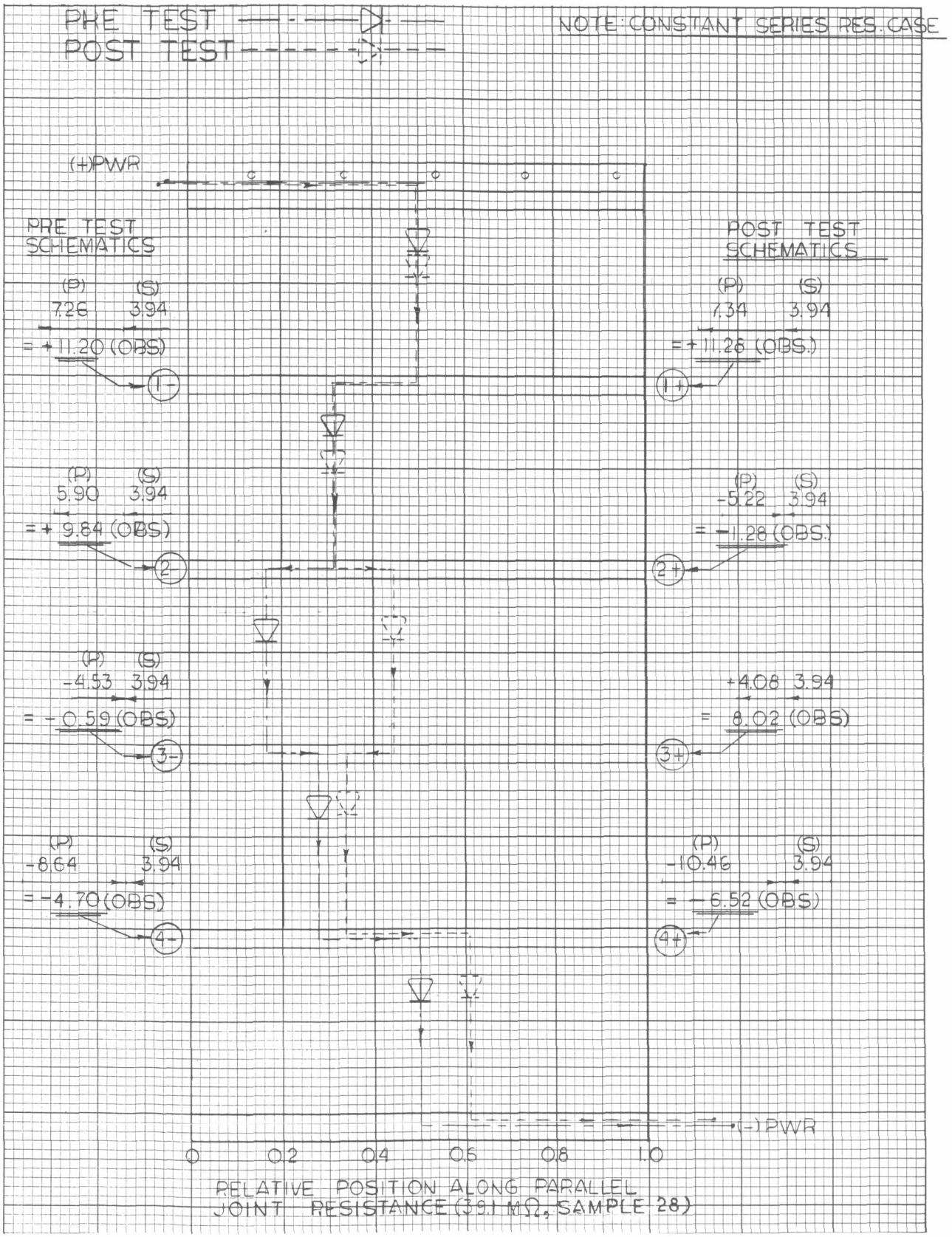


Figure 4-14. Analytical Correlation Model of Shifting Current Path Sample 47 Pre and Post Roll Test Conditions

in Row 4 is probably a measure of the accumulated inconsistencies in the assumptions, the principal one being that the series joints were constant both before and after the roll test. While some inconsistency is evident, it cannot be of much significance or the model would have been more affected.

4.2.4 VACUUM THERMAL CYCLING TEST RESULTS

Two samples were constructed for the Vacuum Thermal Cycling tests. Sample 45 was a soldered assembly and Sample 50 was assembled using conductive epoxy bonding. Sample 45 was subjected to the 24 thermal cycle sequence three times, each with different mechanical tension loads. Sample 50 was subjected to the cycling sequence only once, with the five pound tension loading in the series direction. To obtain cell performance data correlatable to other programs, on 8 hour dwell at operating conditions after cycling was added to the test.

Performance of the samples was monitored by voltage-current curves taken every six cycles. The pattern of the electrical performance, in terms of sample efficiency, is shown on Figure 4-15.

Sample 45, Reinforced Indium-Bismuth Soldered Method

During the 24 cycles with the 5 pound biaxial loading, the efficiency was very stable in the 2.5 to 2.6 percent range. (All performance values based on intensity as established by silicon cell standards since no CdS calibrated standards were on hand. Data must be used on a qualitative basis.) The curves for this sequence were taken with 140 mw/cm^2 intensity. Temperatures at this illumination ran lower than the desired 55^{o}C and a joint decision by the GE Technical Leader and the Lewis Program Manager was made to increase the intensity on succeeding tests until the desired temperature was attained. (For sample 45 the light level achieving 55^{o}C was 147 mw/cm^2, while for sample 50 the required light level was 158 mw/cm^2. This difference probably resulted from variations in the bonding of the thermocouples to the backside of the modules.)

During the second 24 cycles, this time loaded with 5 pounds in the series direction, efficiency of sample 45 was again very stable, although around the 2.1 percent point. The drop in performance from the previous test was a temperature effect rather than a degradation.

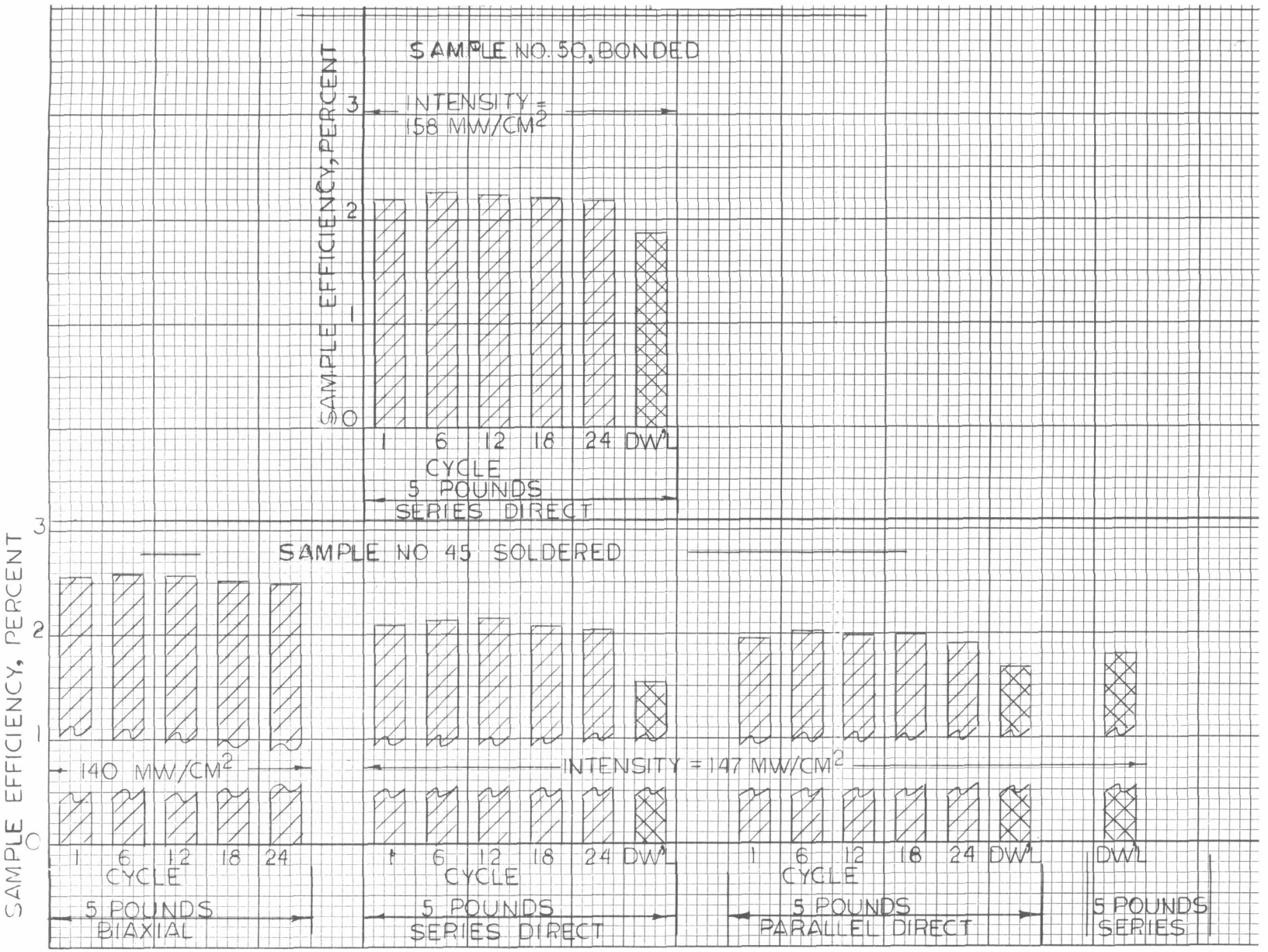


Figure 4-15. Electrical Performance Vacuum Thermal Cycling Tests (Temperature Range - 70°C to 55°C)

Dwell operation, however, did produce a drop in performance, the efficiency falling to 1.54 percent in the late portion of the test. Similar performance drops at sustained temperature operation had been noted by the customer on other programs. The performance degradation experienced during the during the dwell cycle was of a temporary nature and at the initiation of the third 24 cycling sequence (5 pound loading in the parallel direction) the cells had recovered to the 2.0 percent level. Following the third cycling test, a dwell was again performed and again a step drop in performance was observed, although not to the same extent as previously. A final dwell test was performed on sample 45 with performance similar to that observed during the second dwell test.

Sample 50. Conductive Epoxy Bonded

Sample 50 was subjected to the Thermal Cycling-Dwell sequence only once with the mechanical tension load in the series direction, the normal method of loading experienced in the roll-up array application.

Stable performance under cycling conditions was observed with efficiencies in the 2.2 percent range. As with Sample 45, the dwell operation period produced a drop in efficiency to the 1.87 percent point.

Electrical Interconnection Resistance During Thermal Cycling

Interconnection resistance was monitored at several temperatures during each cycle using a current value near 1.0 amps. The values for the same cycles after which I-V curves were taken are shown in Table 4-2. Good joint stability was established as variations in the interconnection resistance were small, ranging a total of 0.90 milliohm for Sample 45 and 0.89 milliohm for Sample 50.

I-V Curves

The I-V curves for both samples taken under the series loading condition are shown in Figures 4-16 and 4-17.

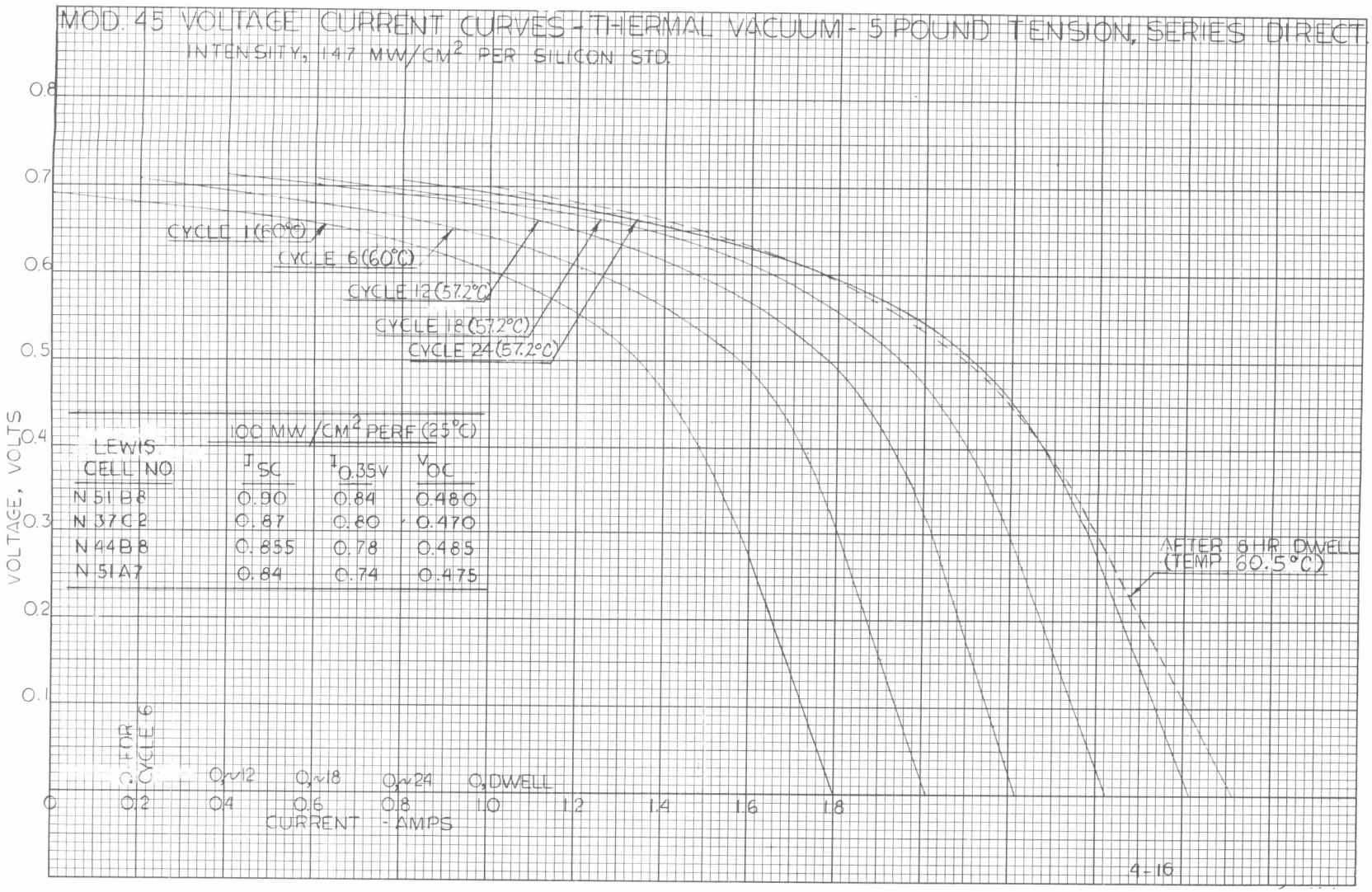


Figure 4-16. Sample 45 Voltage Current Curves - Thermal Vacuum-5 Pound Tension, Series Direction, Intensity = 147 MW/CM^2 Per Silicon Standard

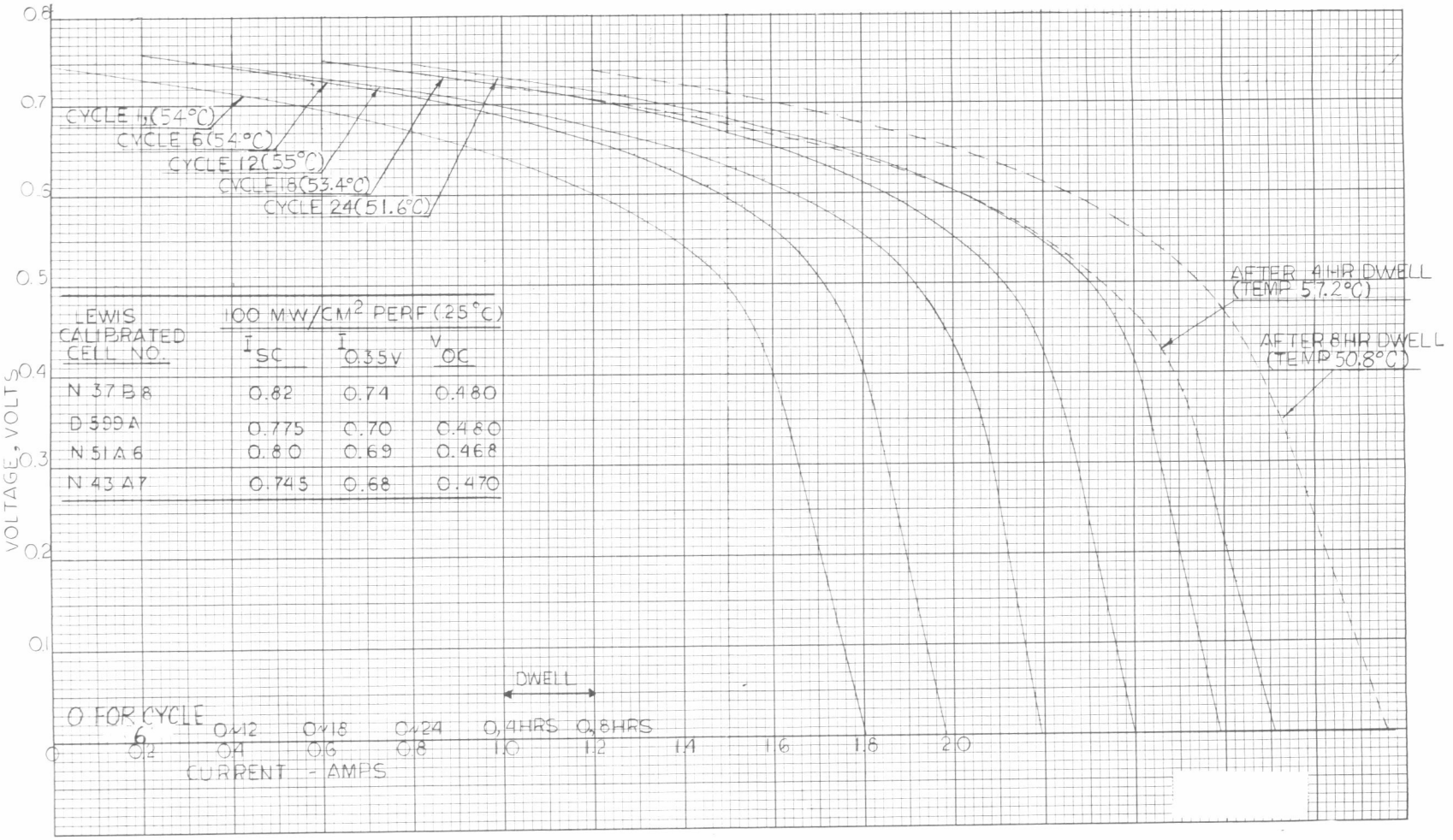


Figure 4-17. Sample 50, Voltage Current Curves-Thermal Vacuum-5 Pound Tension, Series Direction 2 Parallel x 2 Series; SMRD 745 + AG Conditioned Epoxy Bond, Schjell Clad Paralleling, Intensity = 158 MW/CM^2 Per Silicon Standard

Table 4-2. Interconnection Resistance Data Summary - Vacuum Thermal Cycling Tests

Sample No.	Mechanical Loading	55°C Temperature Interconnection Resistance - Milliohms (Observed)					
		Cycle 1	Cycle 6	Cycle 12	Cycle 18	Cycle 24	Dwell
45	5 Pounds Biaxial	-2.35	-2.05	-2.10	-1.93	-1.98	-1.64
45	5 Pounds Series Direction	-1.75	-1.39	-1.95	-1.84	-1.60	-1.69
45	5 Pounds Parallel Direction	-1.72	-1.63	-1.58	-1.45	-1.46	-1.96
50	5 Pounds Series Direction	2.92	2.90	2.22	2.26	2.68	3.11

4.2.5 GENERAL COMMENT ON QUALIFICATION TEST RESULTS

Two joining methods (reinforced soldering and conductive epoxy bonding) and two parallel joint methods (staggered cell and tab connected inline) were evaluated during the specialized qualification program. Each of these had been evaluated in the prior experimental program and were found to be capable of withstanding environments of the type imposed during the roll testing. It is not surprising, in view of the lead in program, that all of the sample configurations tested during the qualification program were successful. The program did produce data showing differences in performance between the approaches, and it is appropriate to perform an evaluation to establish the overall optimum configuration.

Conductive expoxy bonding showed the best overall performance with regard to tensile strength and stability of the tensile strength in a flexural cycling environment. As the electrical resistance of this type of interconnection was in the same range as the soldered interconnection and both were well below the specified goal, the bonding method must be considered equal to the soldering from the resistance parameter standpoint.

Inline Tab Connected paralleling is more desirable than the staggered cell paralleling due to its lower joint resistivity.

The optimum module configuration is therefore the conductive epoxy bonded using the tab inline parallel connection.

SECTION 5

MANUFACTURING DEVELOPMENT

5.1 SUMMARY

The manufacturing development effort resulted in:

- Process studies
- Fixturing for fabricating reinforced soldered or conductive epoxy bonded CdS solar cell modules up to 5 cells wide
- A soldering/bonding machine
- Procedures for fabricating CdS solar cell modules
- Module fabrication
- Module handling and shipping containers

5.2 PROCESS STUDIES

The following processes were investigated during the early stages of this contract. However, due to limited funds and time, they were not completed. Some of the results obtained during these studies show their potential applications to thin film cell joining processes and in some cases may result in reduced module fabrication costs.

5.2.1 REFLOW SOLDERING

Initial procedures used for solder joints to connect cells include the use of Alpha 709 flux and solder preforms. While this method works satisfactorily, it has several disadvantages:

- Placing and keeping preforms inplace between cells requires skill and is difficult to control.
- Removal of residual flux from between the soldered cells is difficult and time consuming.

A solder reflow process was sought to eliminate both of these disadvantages. The reflow method entails a controlled tinning of the cells before joining. This permits efficient flux removal before reflow soldering and also eliminates the use of solder preforms. The tinning may be accomplished by either dip tinning or hand soldering by applying masking to those areas where solder is not wanted. Initial trials showed this process to be both feasible and a potential improvement over the use of solder preforms. Additional development is required to perfect the process.

5.2.2 MASKING TO PREVENT ADHESIVE CONTAMINATION

Various methods of preventing the flow of adhesive onto the active surface of the cells during application and curing operations were tried during test sample fabrication. These methods employ the use of dams and adhesive tape masks and although they are effective, a study was initiated to find a better means of preventing this type contamination. The most promising method employs the use of spray applied coatings which dry to films which may be pealed off. This method of masking cells may also be used as a means of protecting cells throughout the manufacturing cycle.

The method for applying the mask is described below and in Figure 5-1.

a. Place cells in the holding fixture.

b. Clean surface of cell to be coated with a fluorocarbon solvent.

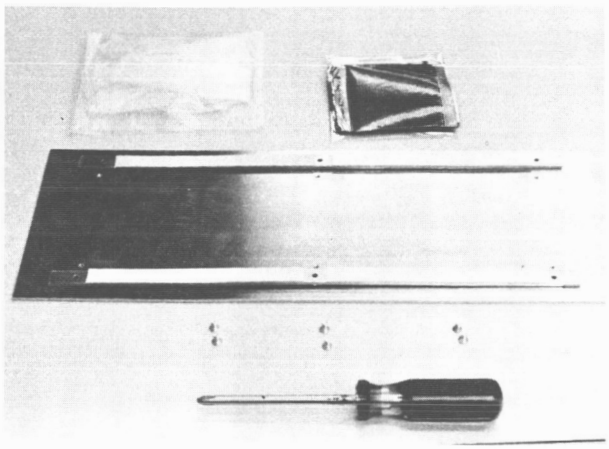
c. Spray a thin even coat over the exposed cell area.

d. Allow to dry

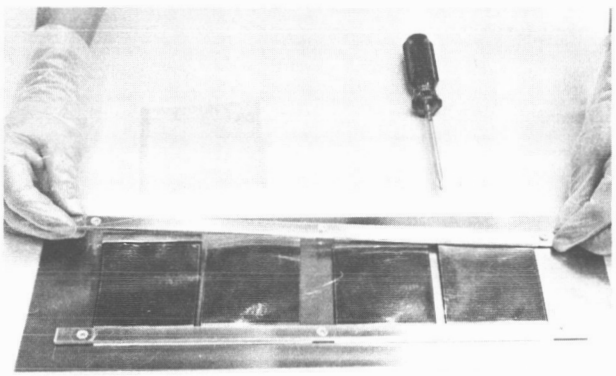
e. Additional coats may be applied, as required, for good coverage and ease of removal allowing sufficient drying between coats.

f. Final cure.

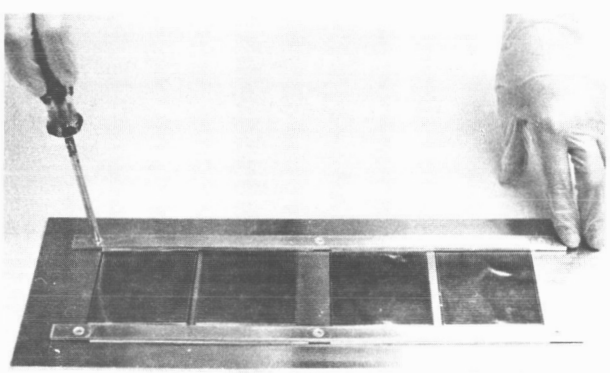
g. Remove cells from fixture and store in tissue or plastic bags until required for assembly.



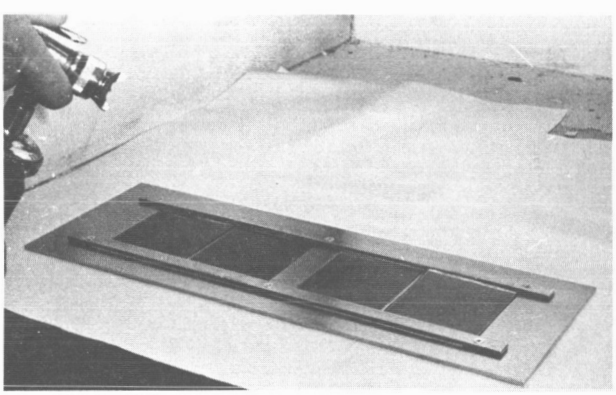
a. Holding Fixture



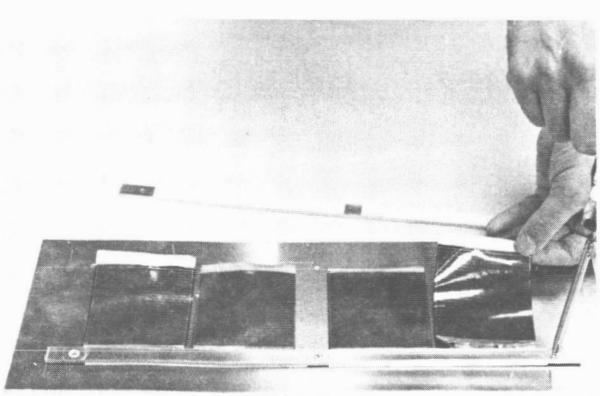
b. Cell Placement



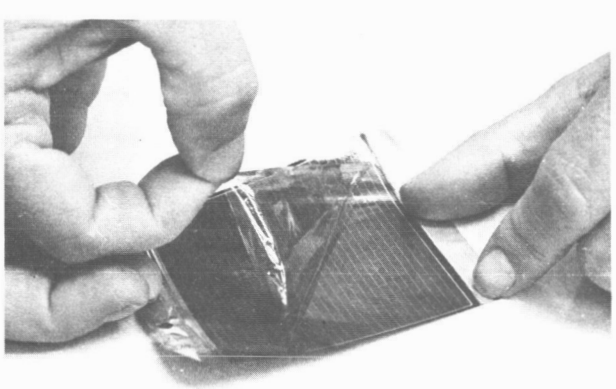
c. Assembly Completed



d. Spraying on Mask



e. Cell Removal



f. Mask Removal

Figure 5-1. Cell Masking Process

Additional studies are required to find a coating material which would be compatible with the Clevite cell and provide maximum protection with easy removal.

Coating materials investigated were:

- Polyvinyl chloride - methanol - water base.

  Discarded due to cell sensitivity to water.

- RTV-60

  Investigation not completed because of funding problem.

5.3 FABRICATION FIXTURE

Because of the multiple steps involved in fabricating both the reinforced soldered and conductive epoxy bonded joints, a fixture was required on which a module could be built up. Since the fabrication process for both methods involves cell alignment and bending of the cell positive tab, a fixture was designed which could be used for either method. The resulting assembly fixture, Figure 5-2, is described in detail in Appendix C.

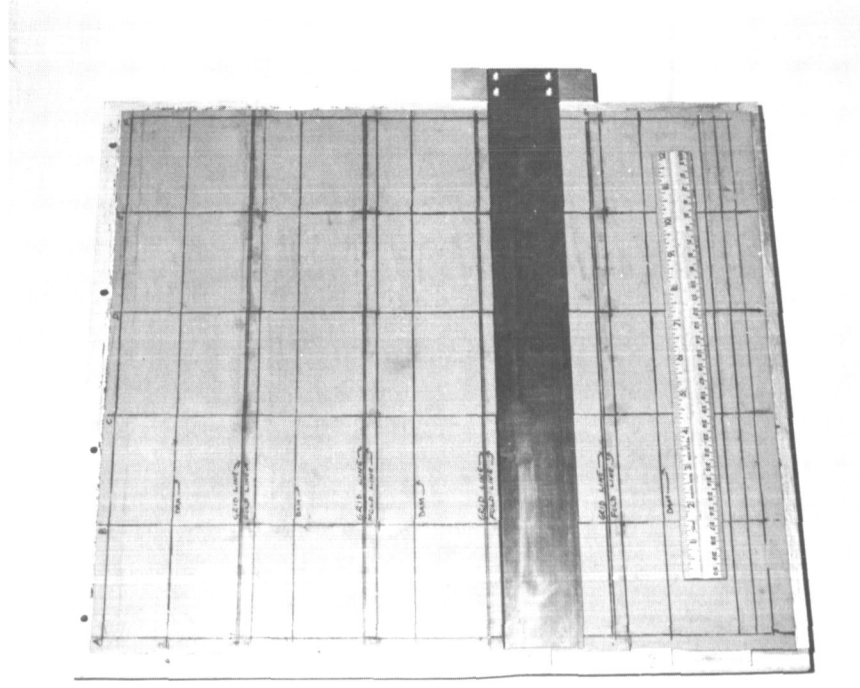


Figure 5-2. Fabrication Fixture

Modules formed by conductive epoxy bonding remain on the assembly fixture during epoxy cure. The module is covered with a piece of foam overlayed by a cover plate. The combination is then clamped together (Figure 5-3) and put in an oven.

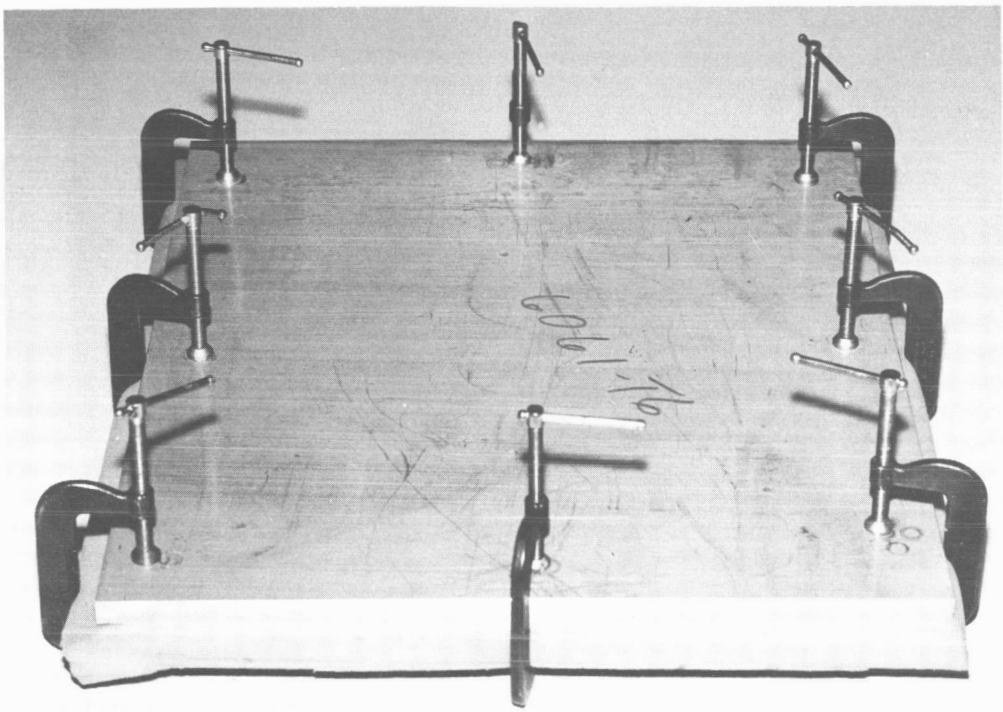


Figure 5-3. Bonded Module Curing Fixture

5.4 SOLDERING / BONDING MACHINE

Experience soldering interconnections during the development process pointed out the need for a piece of equipment capable of making multiple soldered interconnections and long GT-100 bonds. A design patterned after the joint fabrication apparatus shown in Figure 3-6f resulted in the soldering/bonding machine shown in Figure 5-4 with the fabrication fixture in place (details in Appendix C). The machine and assembly fixture can be used to fabricate modules from one to five cells wide and, although designed for modules five cells long, from two cells to five or more cells long.

5.5 PROCEDURES

The general procedures for fabricating both soldered and bonded type modules were worked out during fabrication of both experimental and qualification samples. Since the assembly

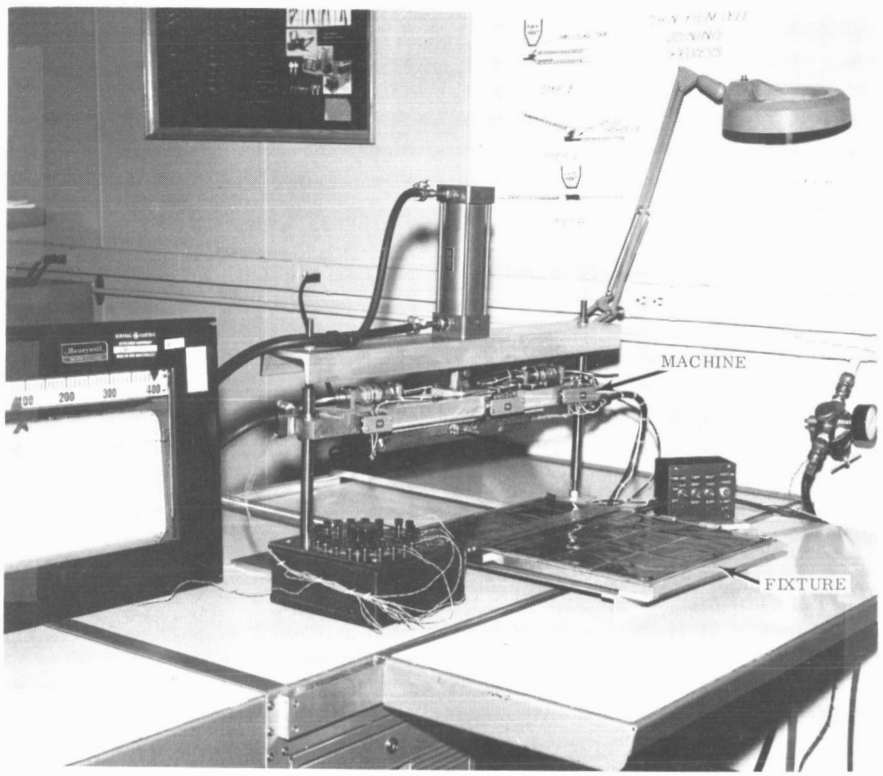


Figure 5-4. Thin Film Solar Cell Soldering/Machine and Module Assembly Fixture

fixture and the soldering/bonding machine were available near the end of the qualification program, the last qualification samples were fabricated using this equipment. This afforded an opportunity to define the procedures which were further refined and finalized during module fabrication. Appendix D contains the detailed procedures for module fabrication.

5.6 MODULE FABRICATION

The culmination of manufacturing development was the fabrication of the eight modules. An accounting was made of the engineering and manufacturing technician labor hours which were directly applied to the fabrication of each of the 25 cell modules. The hours are shown in Figure 5-5 and show that a stronger learning effect was present with the reinforced soldered modules than with the conductive epoxy bonded modules. The curve for the soldered modules seems to indicate only a slight decrease in fabrication time is possible with the present equipment. The curve for bonded modules should, however, be extrapolated with some caution. Using present equipment, indications are that fabrication

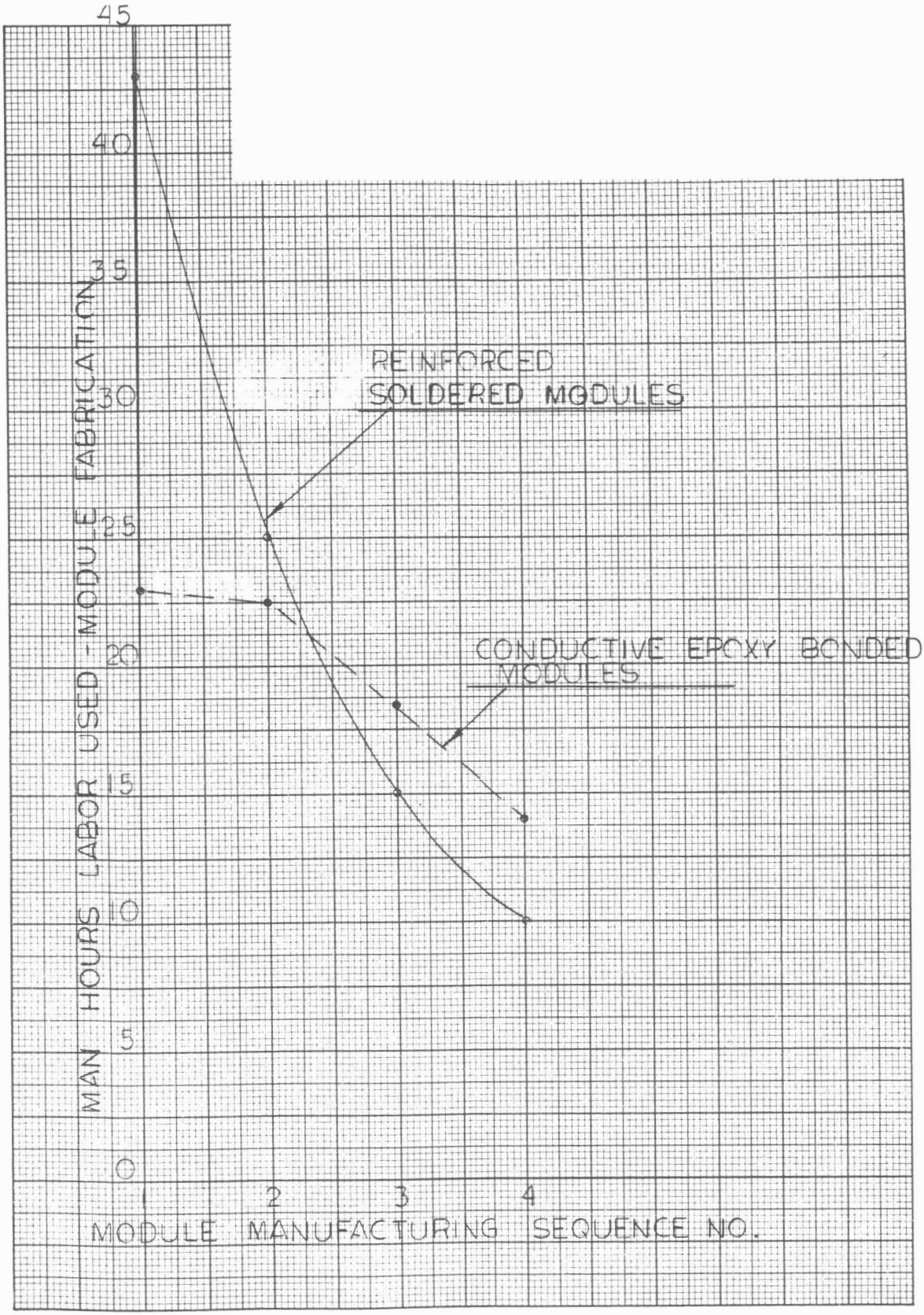


Figure 5-5. Learning Effect on Module Fabrication Time -25 Cell CdS Solar Cell Modules

time will level off at or slightly above that for soldered modules. Some additional equipment and process modifications could offer the bonding method considerable time savings.

5.7 MODULE HANDLING CONTAINERS

An inexpensive versatile container especially for handling and storing modules, constructed of thin film solar cells, was designed and a prototype container constructed. Figure 5-6 shows the construction and features of this container. The principle characteristics of the design are:

- Light weight
- Inexpensive
- Cushioned protection against accidental jarring
- Holds module firmly to prevent shifting during moving
- Protects against dust and other contamination during extended periods of storage
- May be used as a safe shipping container by placing it within a sturdier box

An alternate handling and packaging method was developed and used on this program. In-house handling is accomplished by taping the 5 x 5 cell module to a quarter inch thick plastic sheet. A layer of cushioning insulation is placed on top of the module and a second sheet of plastic serves as a cover. This cover sheet is affixed to the bottom sheet by means of screws or pressure-sensitive tape. For storage and shipment, a tube within a tube is used. A 4 inch cylinder is used as a drum on which the module is rolled. A sheet of cushioning material is placed over the rolled module and this assembly is then placed within a larger (6 inch) cylinder and end closures applied. Examples of these containers are shown in Figure 5-7.

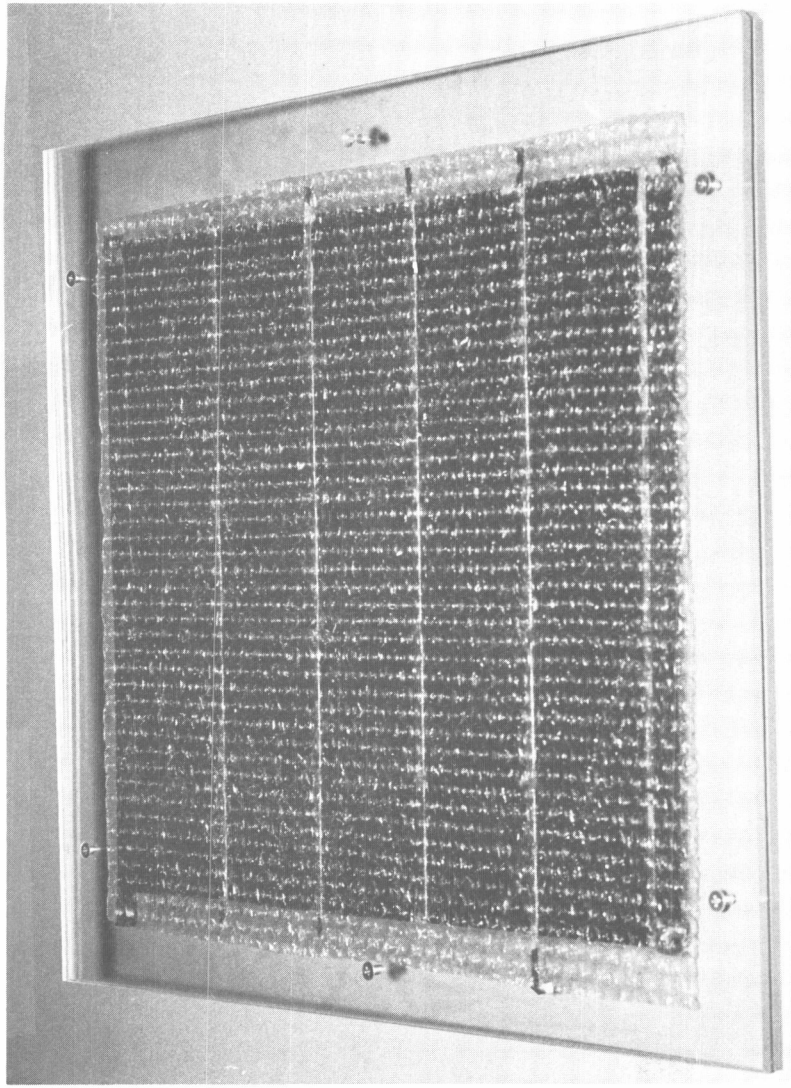


Figure 5-6. Module Handling and Storage Container

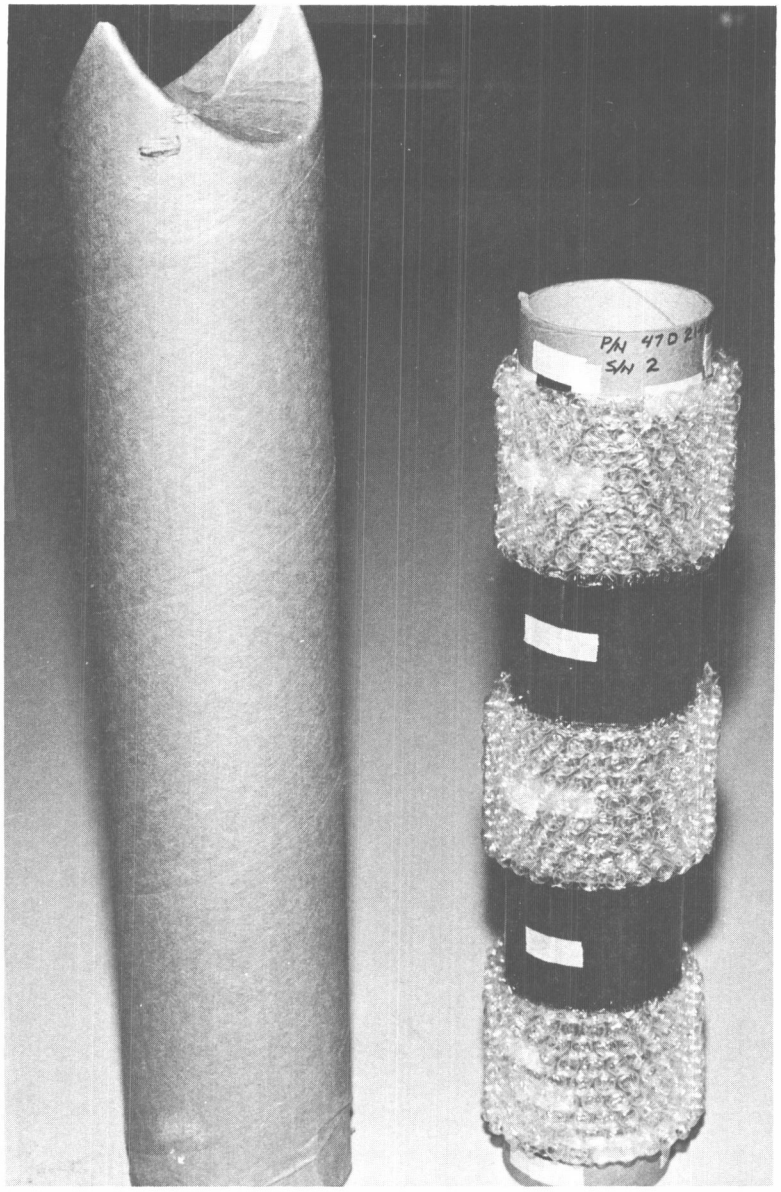


Figure 5-7. Handling, Storage and Shipping Container for Twenty-Five Cell Modules

SECTION 6

25 CELL MODULES

6.1 DESCRIPTION OF 25 CELL MODULES

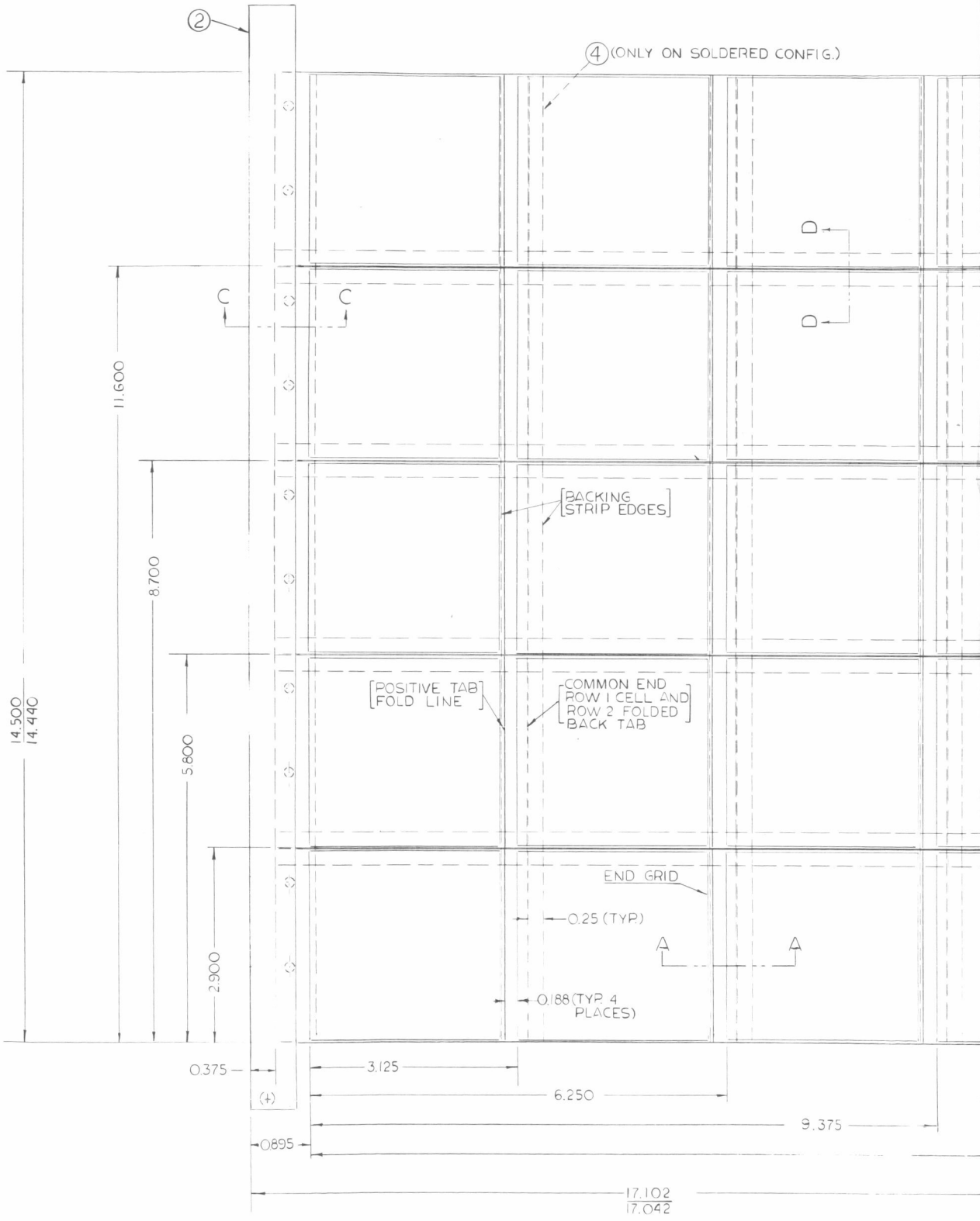
In accordance with the contract, eight modules of 25 CdS solar cells each were manufactured using the processes developed and qualified under the technical program described earlier in this report. Configuration control of the modules was maintained in accordance with Drawing 47D214515, Figure 6-1.

Four of the modules were fabricated by the "Reinforced Soldered" method and four by the "Conductive Epoxy Bonded" method. Following fabrication, the modules were performance tested in natural sunlight. One of the completed units is shown in Figure 6-2 mounted on the solar testing fixture. Results of the solar test, shown in operation in Figure 6-3, were reduced and standardized to a $25^{o}C$ condition to permit comparison between the individual units and between the joining methods.

As with the Vacuum Thermal Cycling Test, the reference standards for the solar testing were silicon cells since stable calibrated CdS standards were not on hand. The silicon standards are referenced to their air mass zero condition.

6.2 ELECTRICAL PERFORMANCE SUMMARY

Observed data from the solar testing of the eight 25 cell modules is shown in Table 6-1. Test conditions were stabilized for both standards and modules by exposing them to the same environment for a considerable period of time. The open circuit voltage characteristic of the silicon cell standard was used to establish the equilibrium temperature and its short circuit current to determine intensity. The "cell thermometer" approach was considered more reliable in view of the time lag and mounting effects which were noted with back-mounted thermocouples in the Vacuum Thermal Cycling test. Thermocouples could be considered for future tests if a high strength and highly conductive mounting configuration were incorporated into the design. As one group of modules was tested under "warmer than standard" conditions and one group was tested under "colder than standard" conditions,



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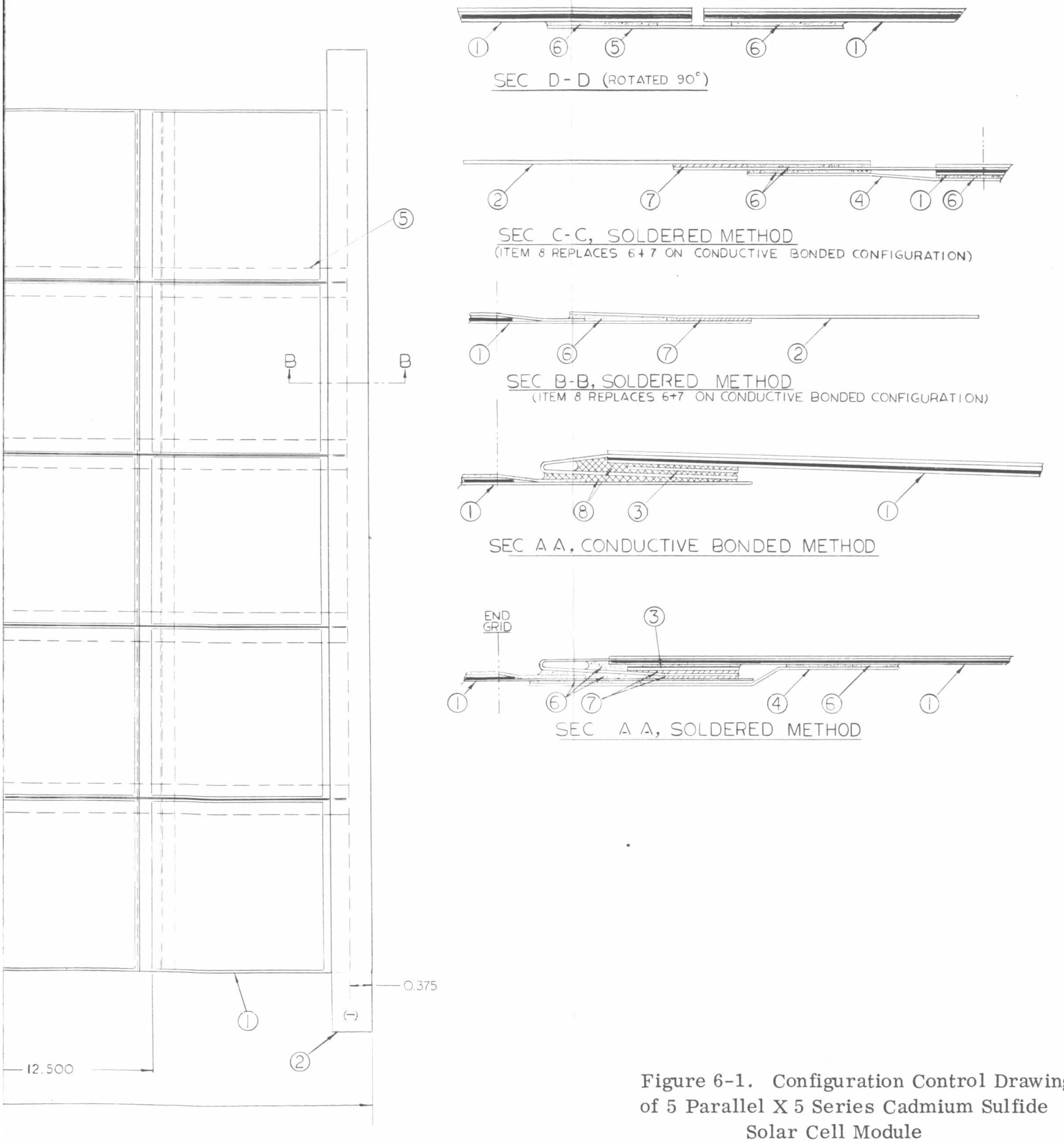

Figure 6-1. Configuration Control Drawings of 5 Parallel X 5 Series Cadmium Sulfide Solar Cell Module

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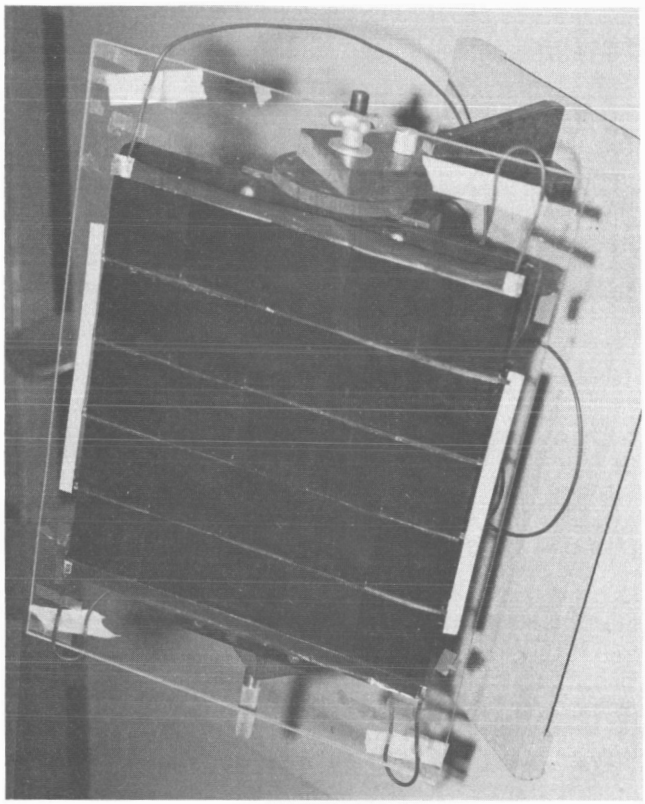


Figure 6-2. Twenty-Five CdS Solar Cell Module Mounted on Solar Test Fixture

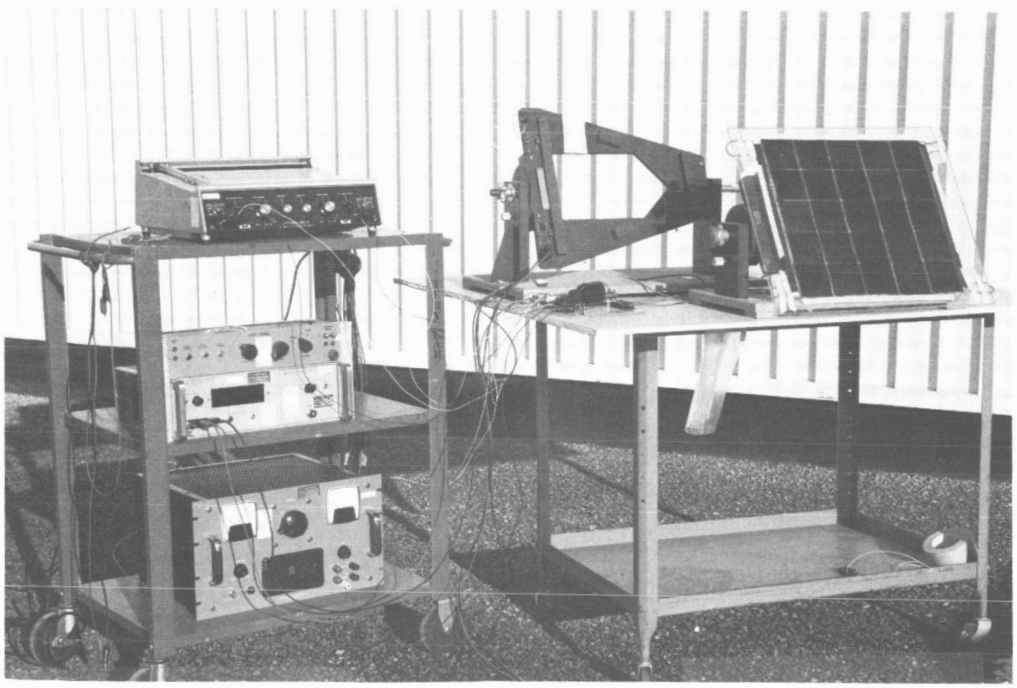


Figure 6-3. Solar Testing Setup for Twenty-Five CdS Solar Cell Modules in Operation

Table 6-1. Solar Test Data - 25 Cell CdS Solar Cell Modules

Module (No. Type)	Temperature (^{o}C)*	Intensity (MW/cm^2) **	Input Energy (watts)	V_{OC} (volts)	I_{SC} (amps)	Peak Power (watts)	Efficiency Percent	Fill Factor, Peak Pwr/ I_{SC}-V_{OC}
1 Soldered	31.2	131.5	179.9	2.30	2.87	4.002	2.218	0.606
2 Soldered	30.7	139.4	190.8	2.34	3.17	4.550	2.384	0.613
3 Soldered	34.5	142.4	195.0	2.33	2.84	4.176	2.141	0.631
4 Bonded	33.4	141.2	193.2	2.29	2.91	4.152	2.148	0.623
5 Bonded	10.4	136.9	187.4	2.44	3.10	4.794	2.558	0.634
6 Bonded	11.8	123.2	168.6	2.43	2.875	4.392	2.604	0.629
7 Soldered	14.3	139.9	191.4	2.38	3.37	4.860	2.533	0.606
8 Bonded	7.2	120.2	164.6	2.42	2.94	4.301	2.613	0.604

*Referenced to Silicon Cell Open Circuit Voltage Standards, AMO
**Referenced to Silicon Cell Short Circuit Current Std, AMO

it was necessary to standardize both to a common standard (25°C specified by the Lewis Program Manager) in order to compare performances effectively. The 25°C standardized data, in Table 6-2, shows that the performance of all eight modules was extremely similar ranging in efficiency from 2.240 to 2.450 percent. The V_{OC} and $P_{max.}$ temperature correction factors, as determined by the Lewis Research Center, were 1.75 mv/°C and 1.8 mw/°C, respectively.

On the basis of performance, the soldered and bonded modules must be considered equal.

6.3 WEIGHT OF 25 CELL MODULES

The weight goal of the program was to accomplish the joining of CdS solar cells with a maximum added weight of 0.03 gram per cell edge, or, for a 25 cell module, 3 grams. Weight data generated from the piece parts and from the finished modules are shown in Table 6-3. Column 1 shows the total weight of the modules complete with end tabs in accordance with Dwg 47D214515. Column 2 shows the added weight attributable to the interconnections and backing strips and shows the degree of attainment of the weight goal. While neither method met the 3 gram maximum goal, the bonded construction at 6.23 grams average was considerably closer than was the reinforced soldered construction which averaged 12.18 grams.

Since the module configuration of Dwg 47D214515 is not representative of the module as it would be used in a minimum weight array design in that it has module interconnection tabs at both ends, the total weight numbers were reduced by one end tab and presented in Columns 3 and 4 for reference. Specific weights of the minimum weight design module are presented in Column 5 in terms of pounds per square foot.

Table 6-2. 25 Cell CdS Solar Cell Module Data Standardized to 25°C Conditions

Module No., Type	$I_{Peak\ Power}$, Amps (Observed)	$V_{Peak\ Power}$, Volts (Observed)	Voltage Correction	Standardized Data - 25°C		Efficiency, Percent (25°C)
				$V_{Peak\ Power}$ (25°C)	Peak Power, Watts (25°C)	
1 Soldered	2.3	1.74	+0.054	1.794	4.126	2.293
2 Soldered	2.5	1.82	+0.0498	1.870	4.675	2.450
3 Soldered	2.4	1.74	+0.0835	1.823	4.376	2.244
4 Bonded	2.4	1.73	+0.0735	1.803	4.328	2.240
5 Bonded	2.55	1.88	-0.1280	1.752	4.468	2.383
6 Bonded	2.4	1.83	-0.1155	1.714	4.115	2.440
7 Soldered	2.7	1.80	-0.0990	1.701	4.593	2.398
8 Bonded	2.3	1.87	-0.1555	1.714	3.943	2.396
Average standardized efficiency - soldered modules						2.346
Average standardized efficiency - bonded modules						2.365

Table 6-3. Weight Data - 25 Cell CdS Cell Modules

Module (No., Type)	Total Weight (Grams)	Added Weight, * Interconnections and Backing (Grams)	Module Design Weight = Total Less One End Tab (Grams)	(Pounds)	Module** Specific Weight (Pounds/Ft^2)
1 Soldered	54.00	11.94	52.39	0.1155	0.0703
2 Soldered	54.56	12.50	52.95	0.1168	0.0711
3 Soldered	54.40	12.34	52.79	0.1164	0.0708
4 Bonded	50.45	8.39	48.84	0.1077	0.0655
5 Bonded	48.50	6.44	46.89	0.1034	0.0629
6 Bonded	47.26	5.20	45.65	0.1007	0.0613
7 Soldered	54.00	11.94	52.39	0.1155	0.0703
8 Bonded	46.95	4.89	45.34	0.1000	0.0608
Avg. Soldered	54.24	12.18	52.63	0.1160	0.0706
Avg. Bonded	48.29	6.23	46.68	0.1030	0.0626

*Total weight less 38.84 grams, cell weight, and less 3.22 grams weight of both end tabs
**Based on module dimensions of 16.322 inches x 14.500 inches = 1.6435 ft^2

6.4 JOINT THICKNESS

Thickness goals for the interconnection joint were stated in terms of the thickness of each layer of two types of joints; 0.002 inch for cured adhesives which includes the soldered joint, and 0.0025 inch for adhesive tapes.

These goals applied to the soldered Joint (Sec A-A, Dwg 47D214515, Figure 6-1) and to the conductive bonded joint (Sec B-B, Dwg 47D241515) result in the following total joint thicknesses.

Soldered Joint Thickness (Sec A-A)

Cells and Folded Back Tab	0.0065
Seam Backing Adhesive Tape	0.0025
P Tab to N Tab Soldered Joint	0.0020
P Tab to Par. Tab Soldered Joint	0.0020
Schjel Clad Paralleling Tab	0.0010
GT100 Bond of Folded Back Tab	0.0020
Total Joint Thickness (Nominal)	0.0160

Conductive Bonded Joint Thickness (Sec B-B)

Cells and Folded Back Tab	0.0065
P Tab to N Tab Conductive Bond	0.0020
P Tab to Parallel Tab Cond Bond	0.0020
Schjel Clad Paralleling Tab	0.0010
Fold Back Bond	0.0020
Total Joint Thickness (Nominal)	0.0135

Joint thickness measurements were taken on the final module of each type construction to determine the degree to which the thickness goals were attained.

Joint Thickness - Module 7 - Reinforced Soldered (Goal 0.015 inch max)

Joint 1	0.021 max	-- 0.015 min
Joint 2	0.022 max	-- 0.018 min
Joint 3	0.019 max	-- 0.018 min
Joint 4	0.019 max	-- 0.017 min

Average of the eight minimum and maximum points = 0.0186 nominal thickness

Joint Thickness Module 8 - Conductive Epoxy Bonded (Goal 0.0135 inch max)

Joint 1	0.013 max	--	0.010 min
Joint 2	0.014 max	--	0.012 min
Joint 3	0.012 max	--	0.012 min
Joint 4	0.013 max	--	0.012 min

Average of the eight minimum and maximum points = 0.0111 In. nominal thickness

The conductive bonded joints met the thickness goal while the soldered joints were over the limit by 0.0036 inch nominally.

6.5 I-V CURVES OF 25 CELL CdS SOLAR CELL MODULES

The Current-Voltage curves obtained for each of the 25 cell modules during the solar performance test are shown in Figures 6-4 through 6-11.

6.6 GENERAL COMMENT ON 25 CELL CdS SOLAR CELL MODULES

The manufacturing processes worked out during the experimental and qualification portions of the program and implemented by the assembly fixture proved very successful in the module fabrication portion of the program. The modules were dimensionally uniform; their electrical performance was uniformly consistent. The efficiency of the manufacturing operation increased quickly to reasonable assembly times and some improvement is still in sight. Overall, the operation layed an excellent foundation for the fabrication of large numbers of standard modules such as would be required for a flight array. Figure 6-12 shows the construction of an array subpanel using four modules. Processes used in the subpanel interconnection and joining are the same as used in the reinforced soldered module.

Generally the conductive bonded modules appear to be the more desirable of the two types. They more nearly meet the weight and joint thickness goals, are stronger and more stable mechanically, and are equal in electrical performance to the soldered modules. The only area where the soldered module showed an advantage was in the rate of the learning curve and in the manufacturing time for the third and fourth modules. This manufacturing time advantage for the soldered assembly, it is anticipated, would be maintained for a larger volume production, for while there are more steps in the soldering assembly sequence, they are generally much less time consuming.

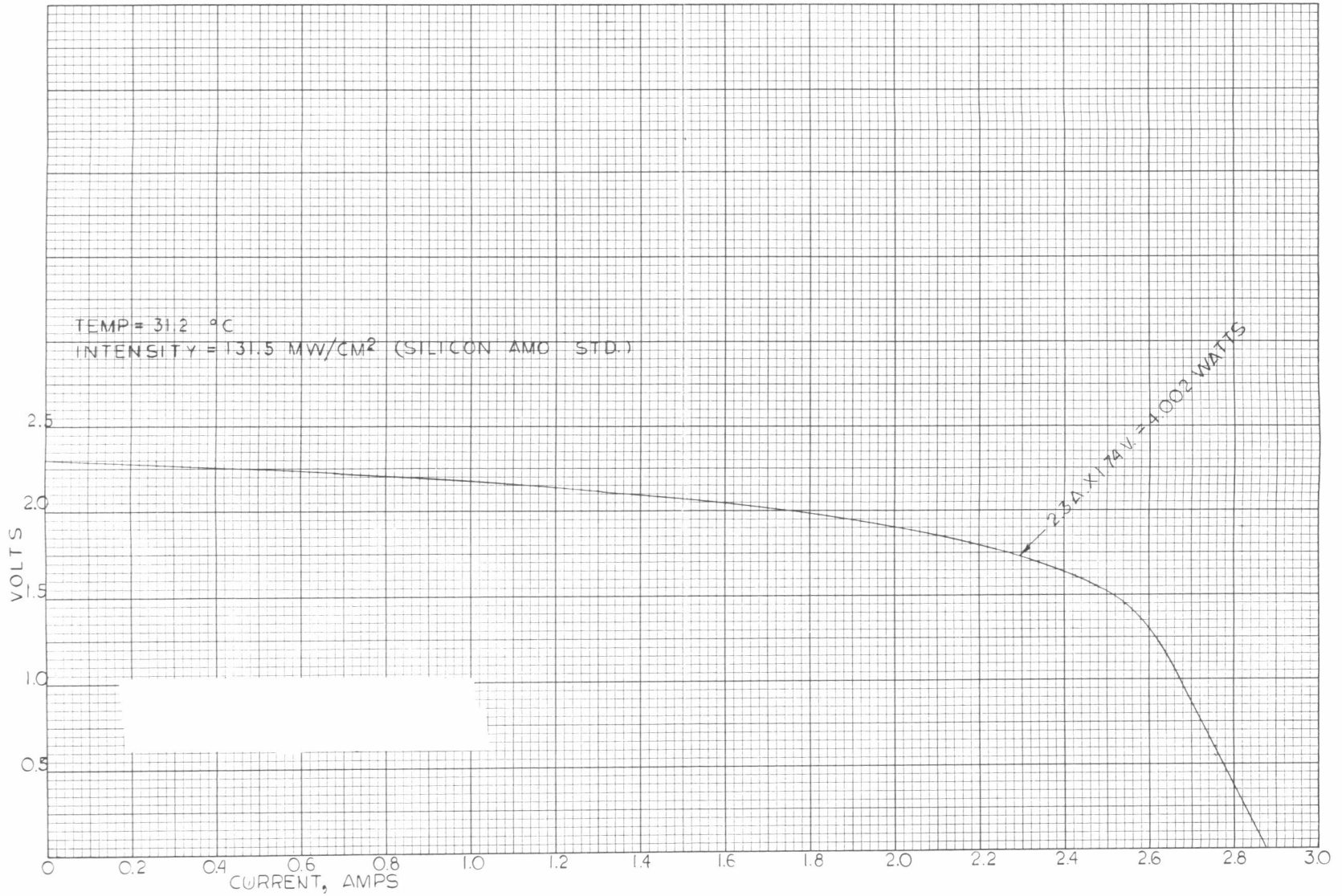


Figure 6-4. Module S/N 1
Solar Test 1-V Curve

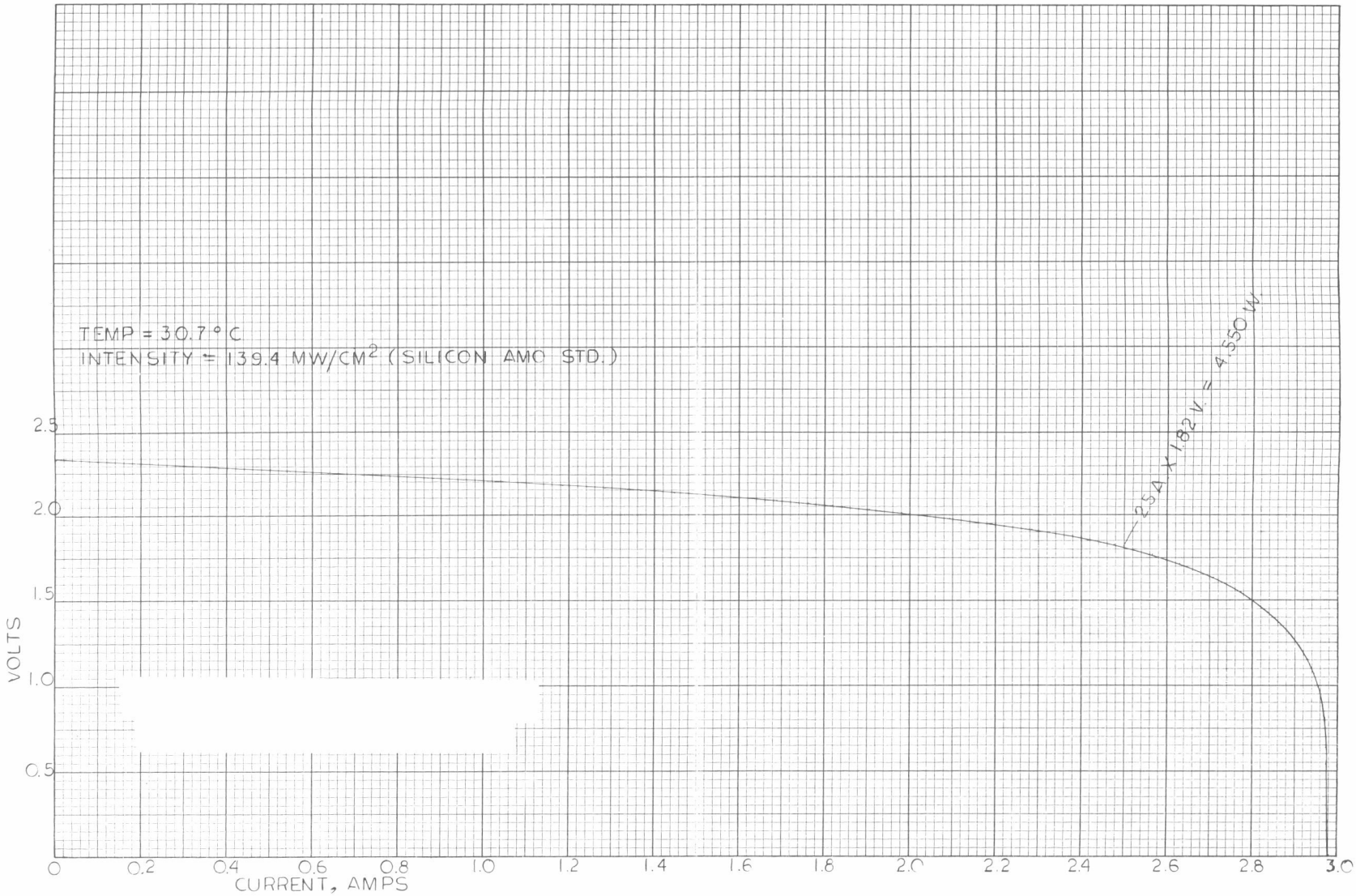


Figure 6-5. Module S/N 2
Solar Test 1-V Curve

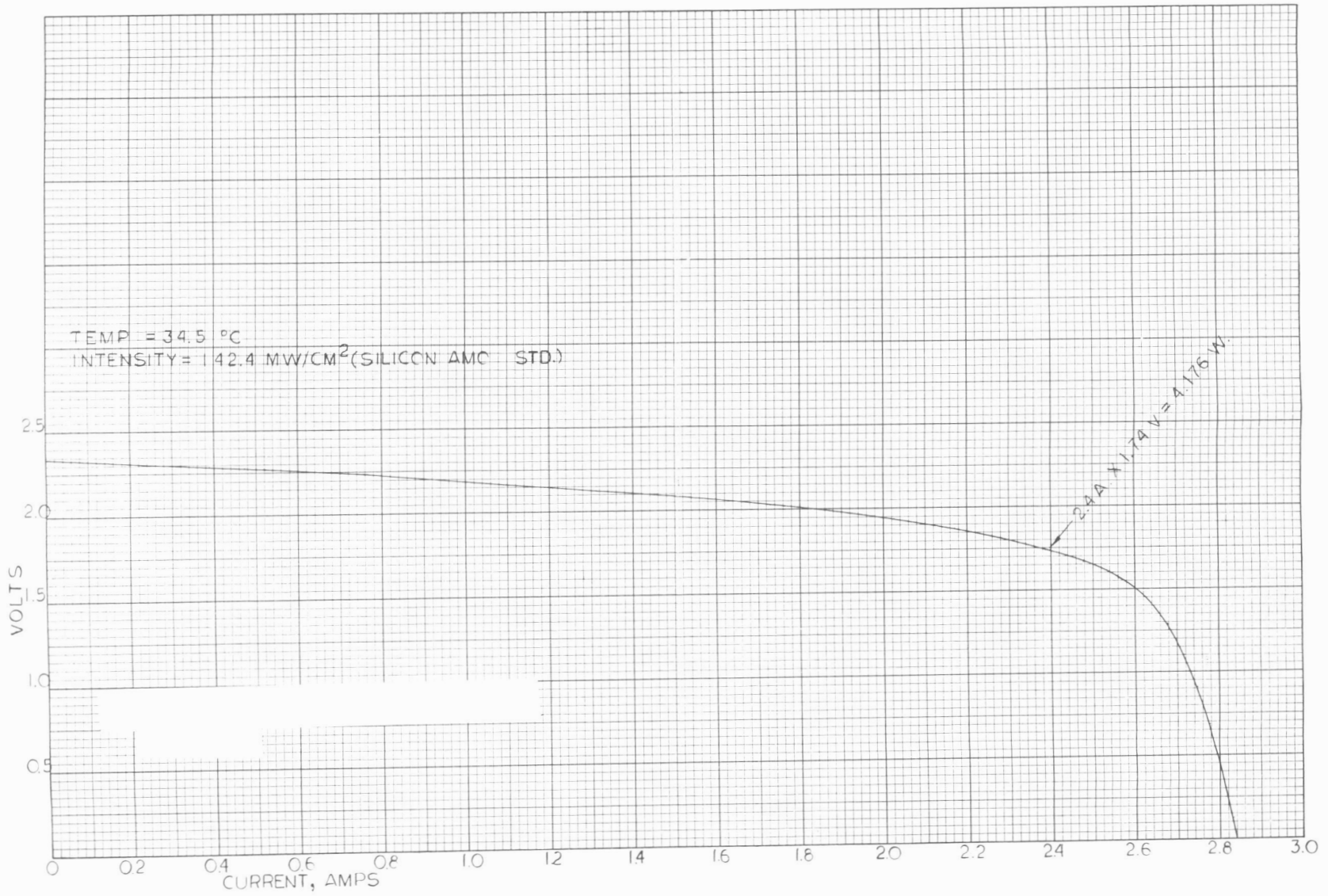


Figure 6-6. Module S/N 3
Solar Test 1-V Curve

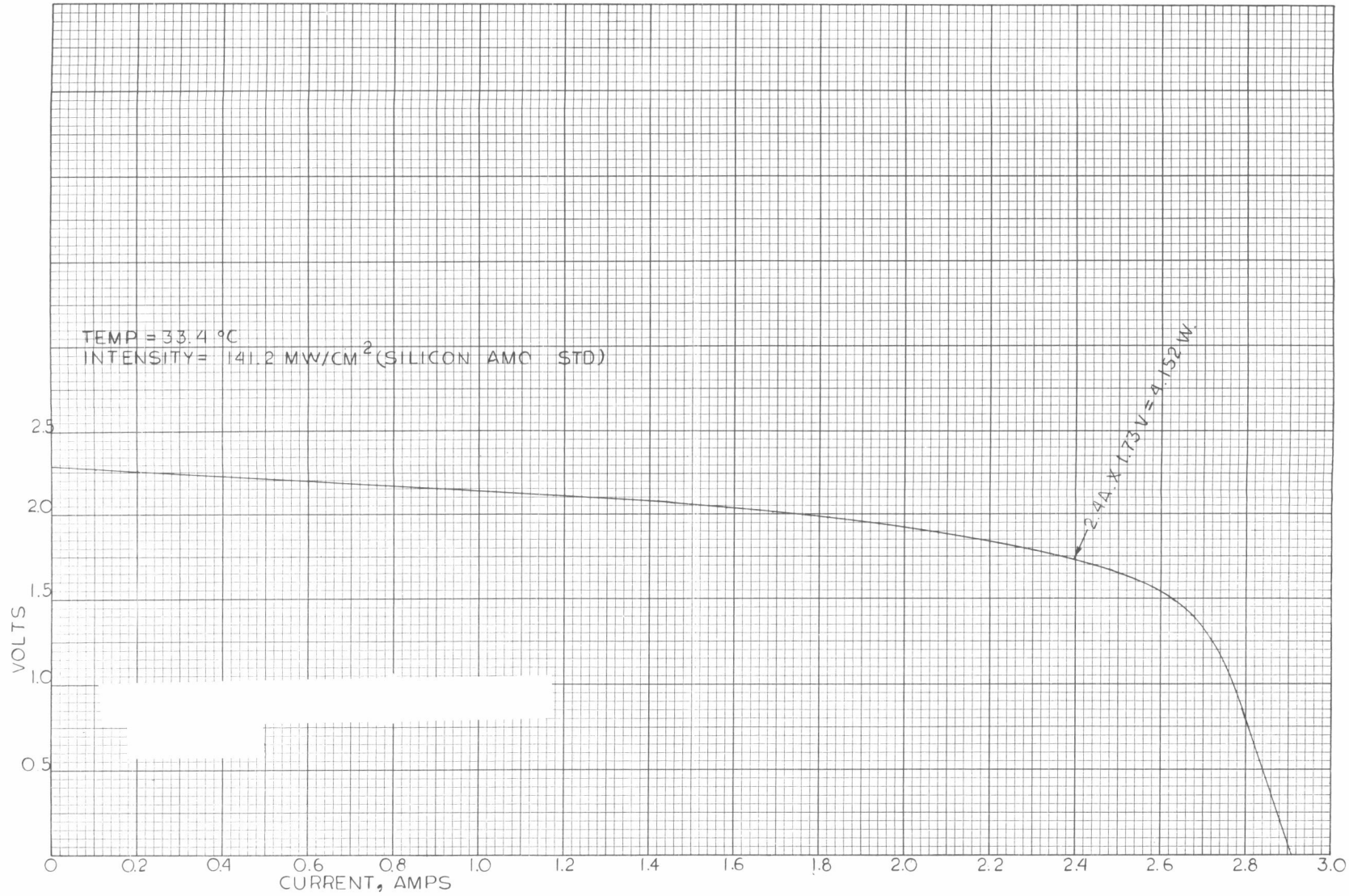


Figure 6-7. Module S/N 4
Solar Test 1-V Curve

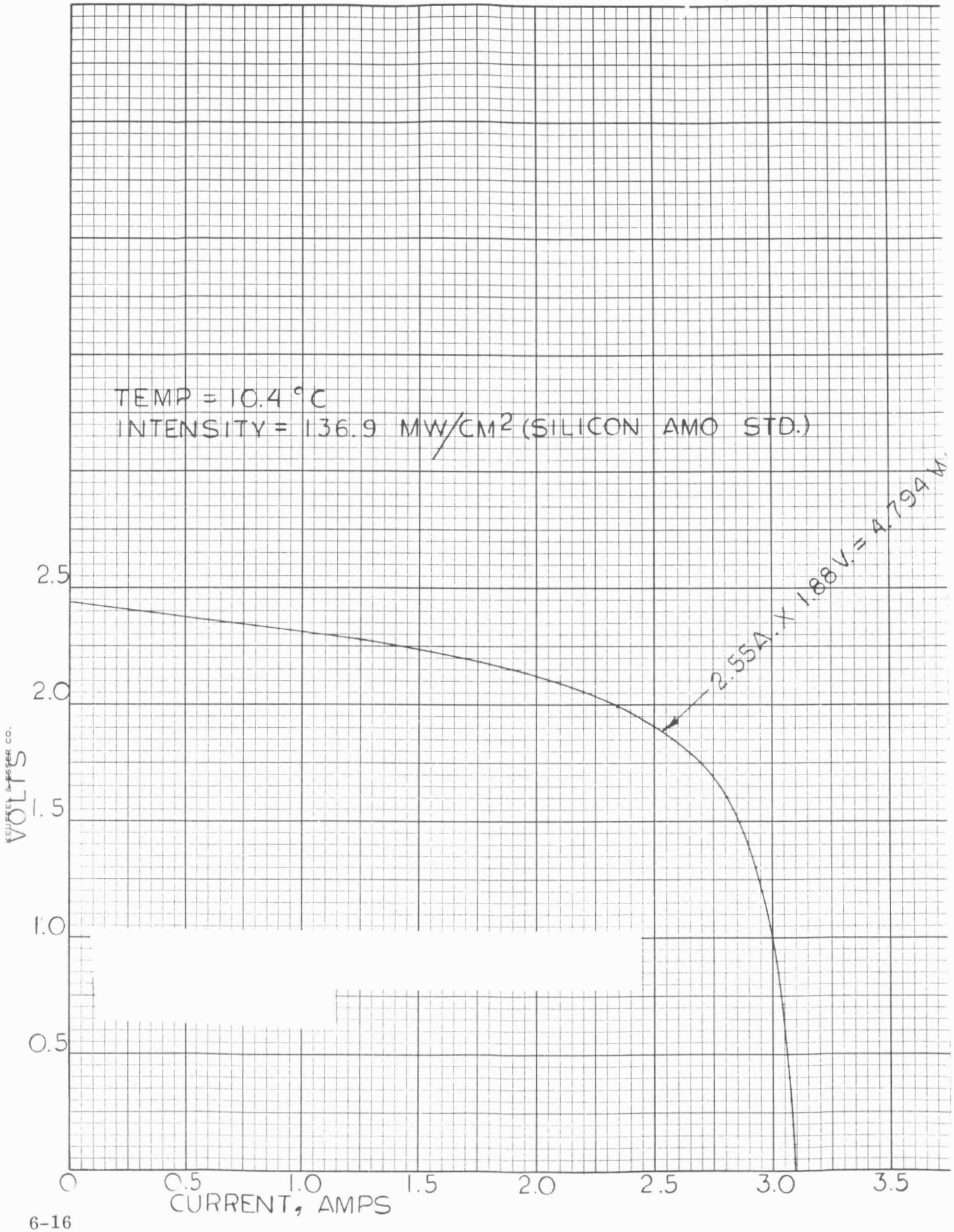


Figure 6-8. Module S/N 5

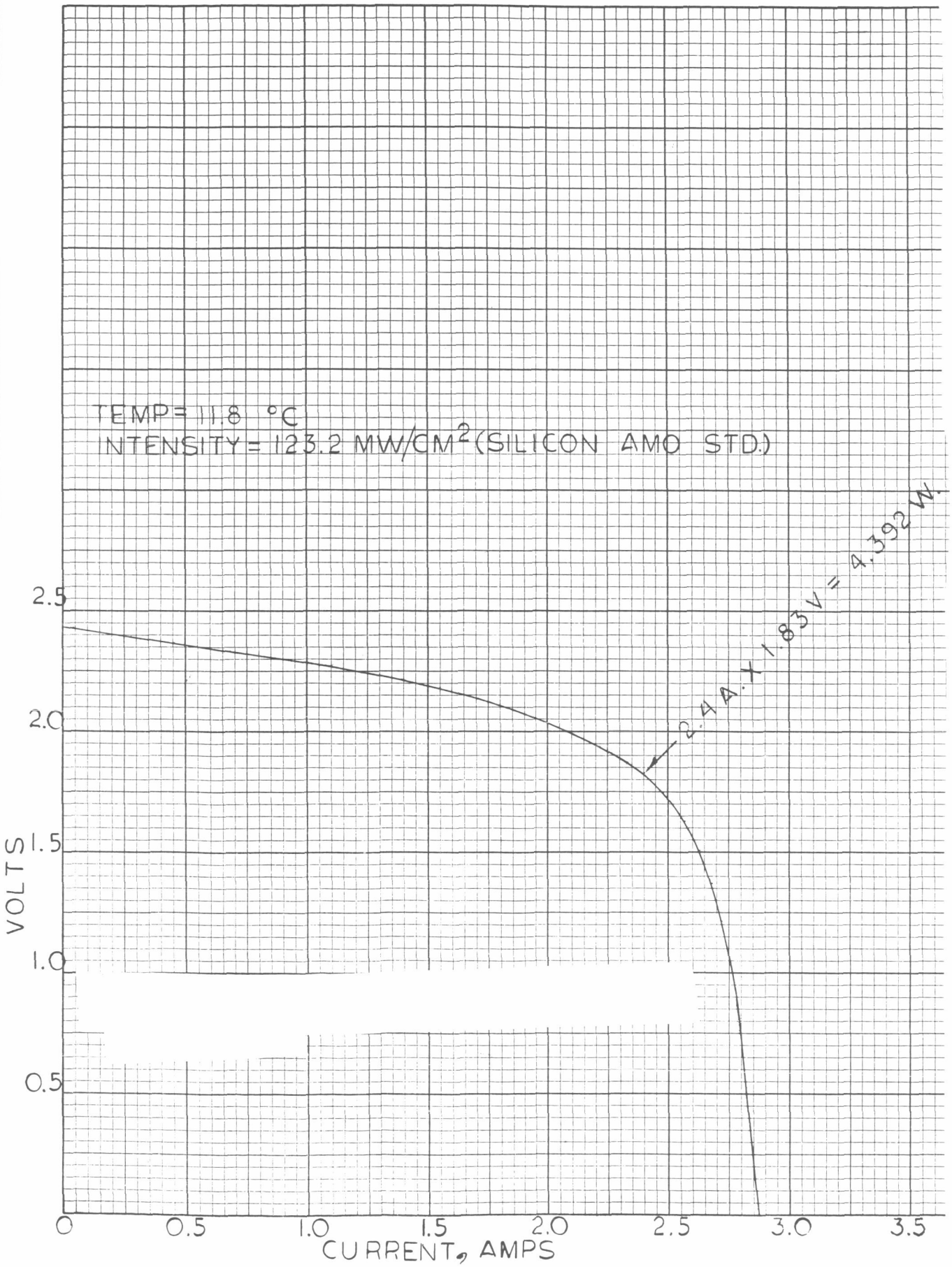


Figure 6-9. Module S/N 6
Solar Test I-V Curve

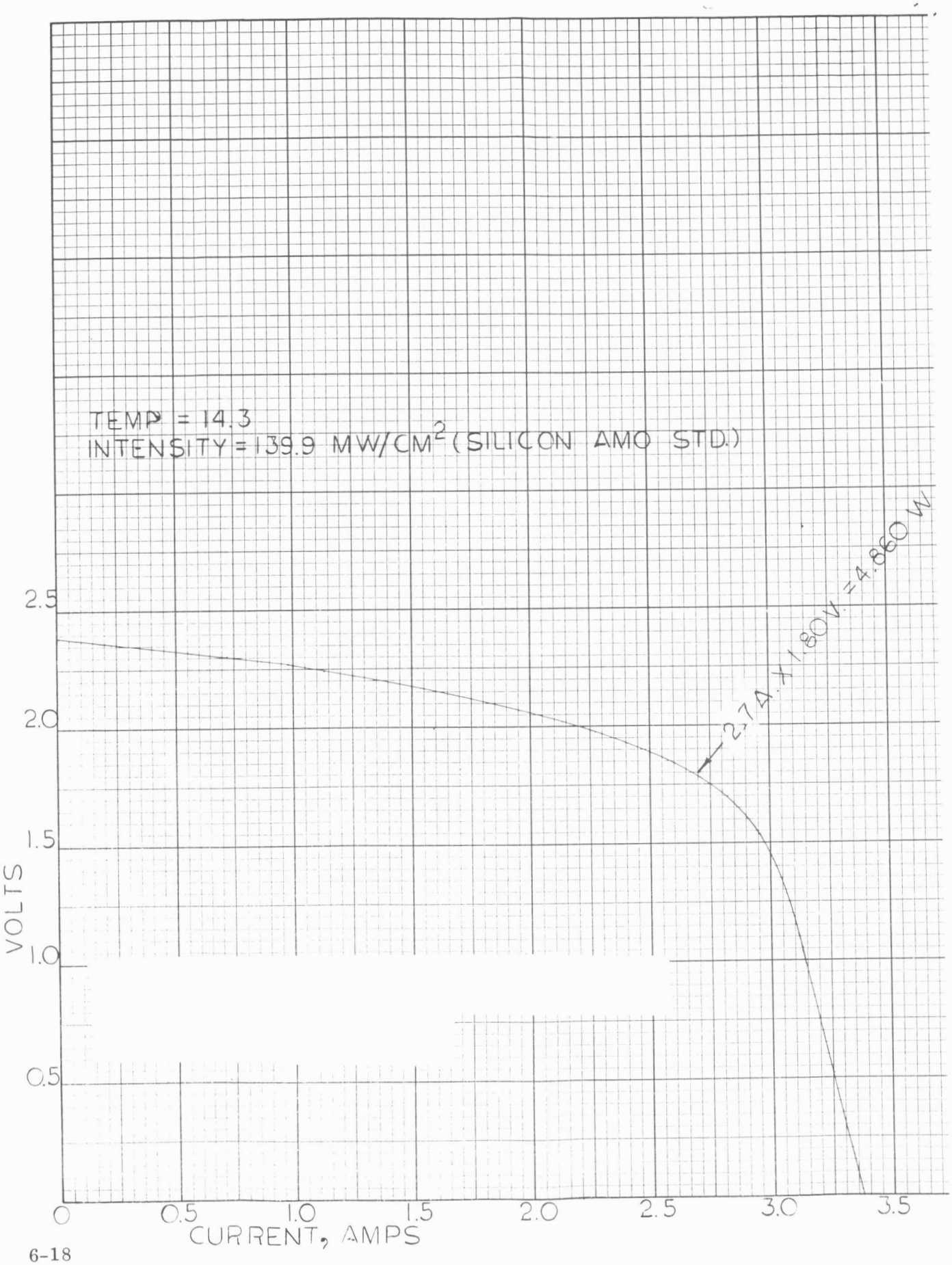


Figure 6-10. Module S/N 7
Solar Test I-V Curve

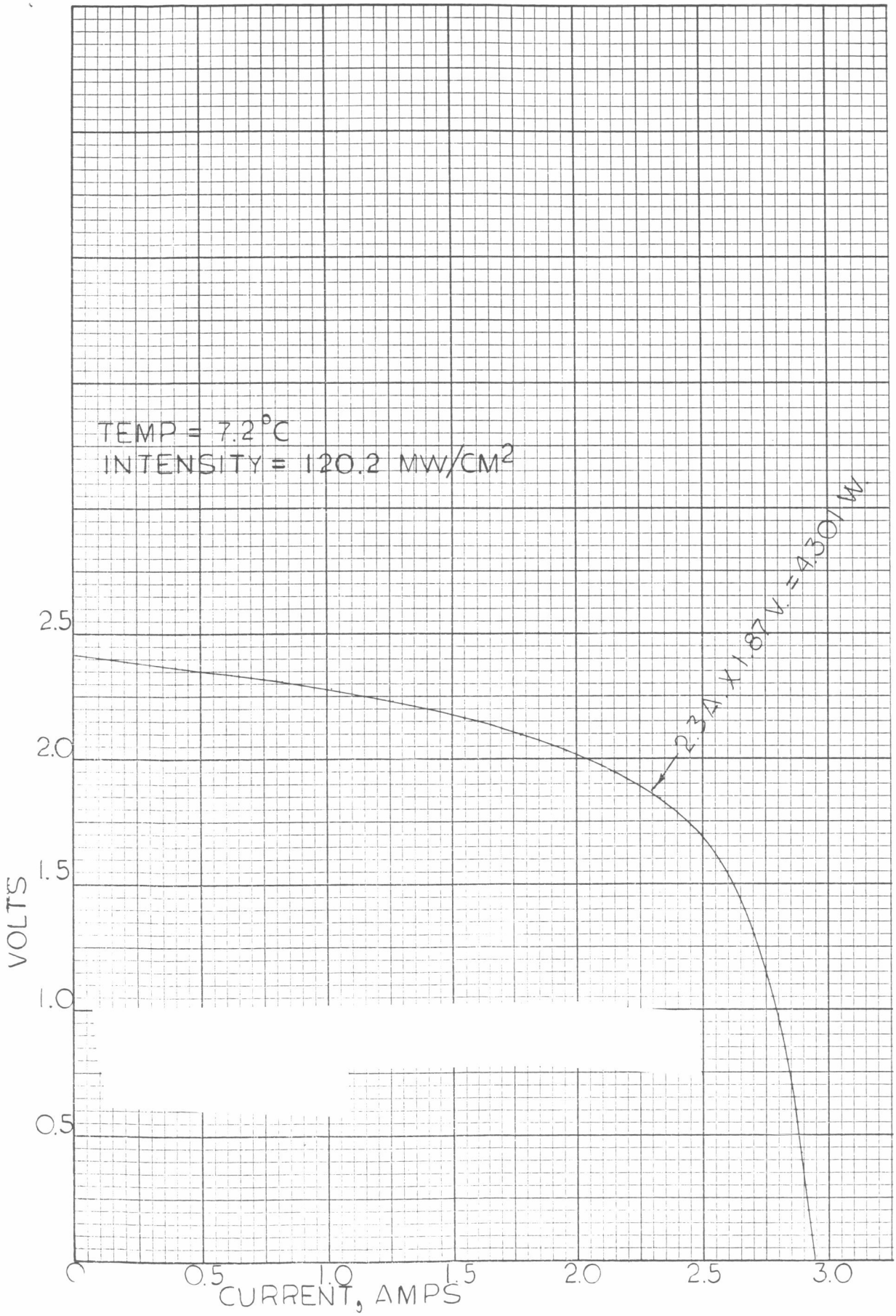
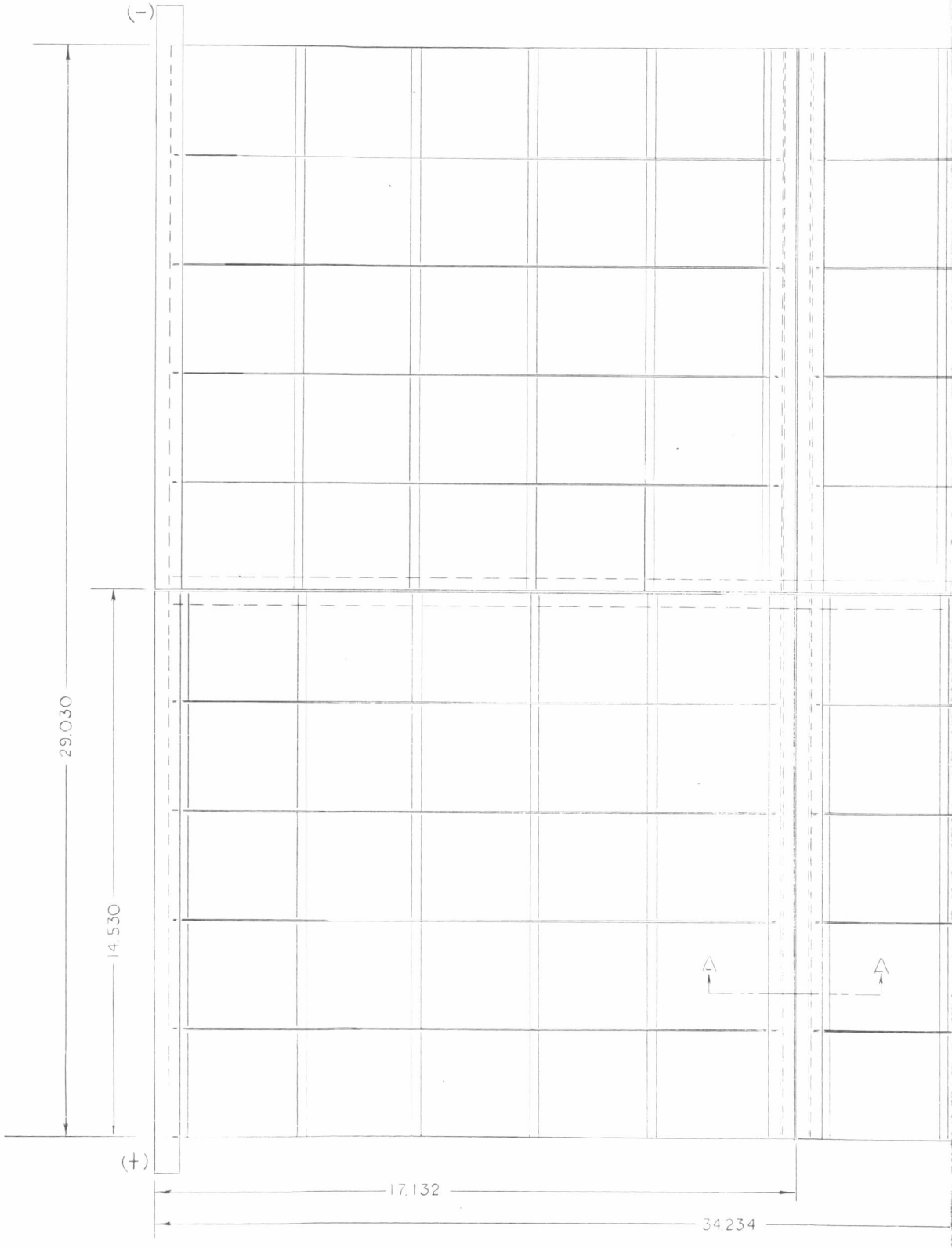


Figure 6-11. Module S/N 8
Solar Test I-V Curve



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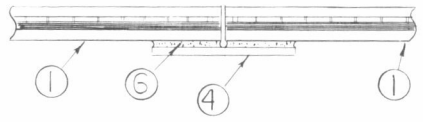
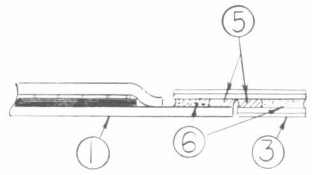
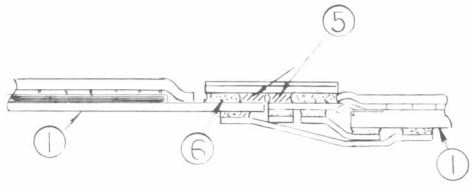


SEC C-C



SEC. B-B



SEC A-A

Figure 6-12. CdS Solar Cell Sub-Panel

APPENDIX A

SUPPLEMENTARY DETAIL DATA GENERATED DURING EXPERIMENTAL AND QUALIFICATION TESTING

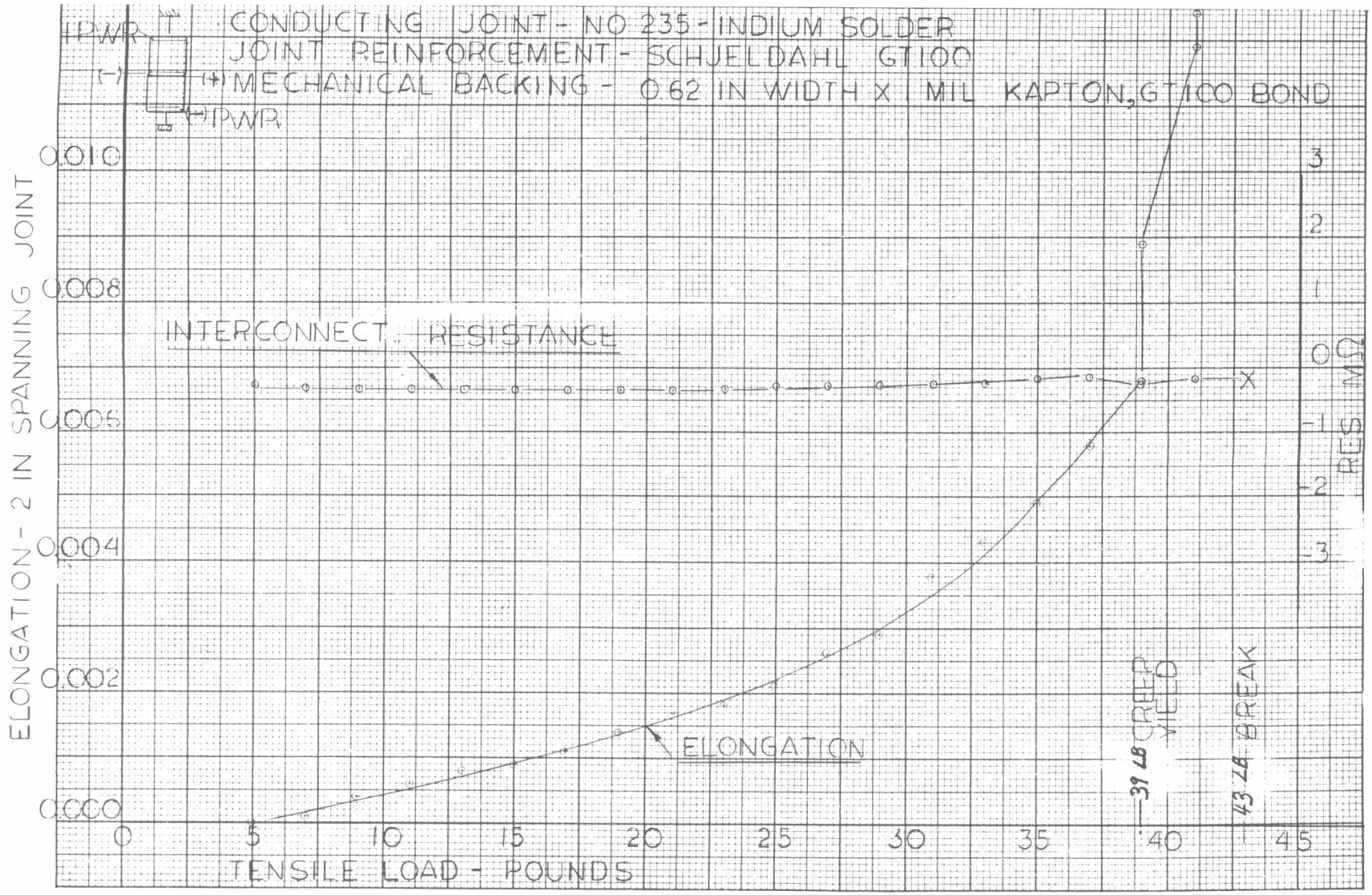


Figure A-1. Sample 35: Ultimate Tensile Test, Series (Y) Axis

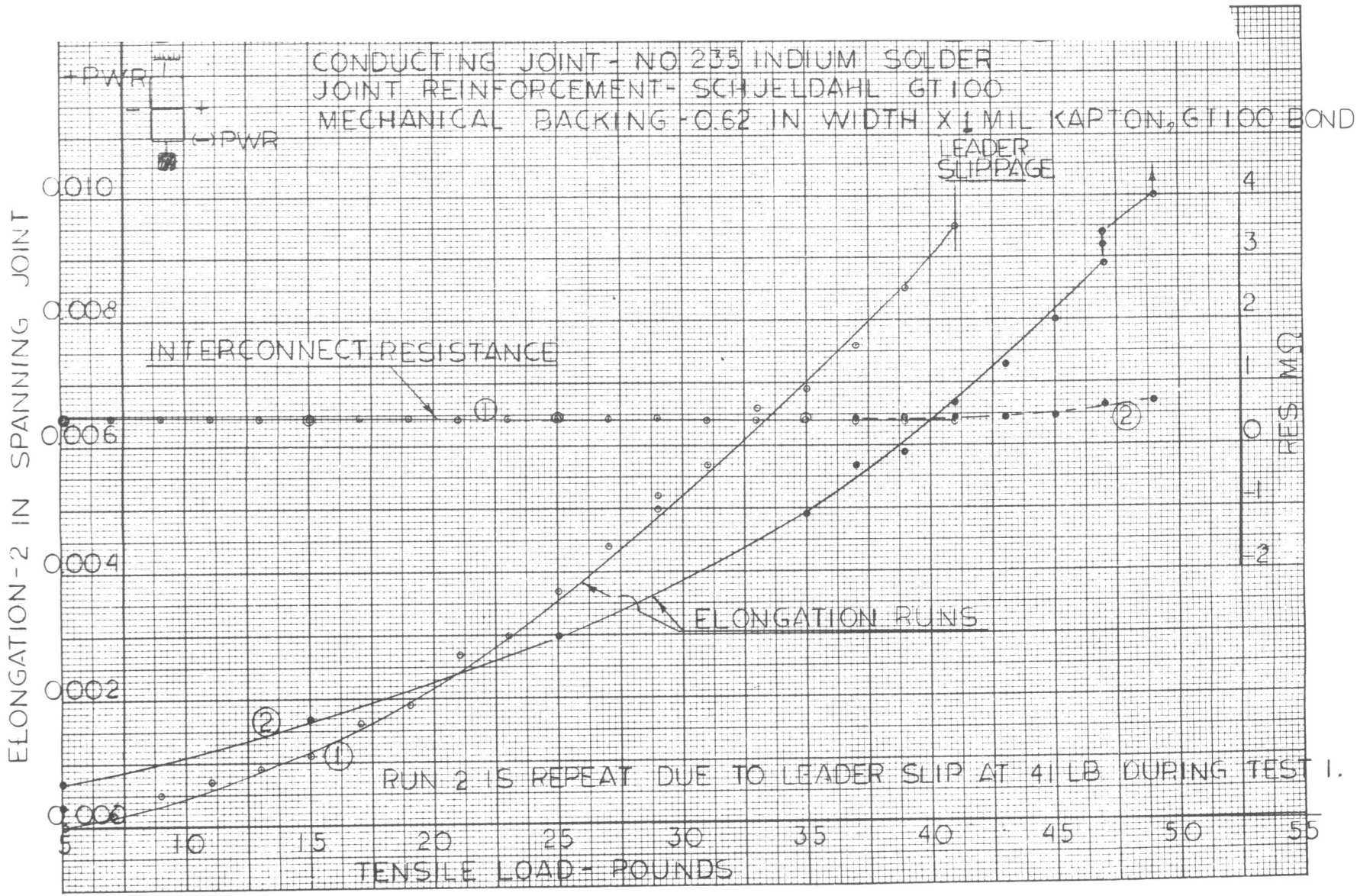


Figure A-2. Sample 36: Ultimate Tensile Test, Series (Y) Axis

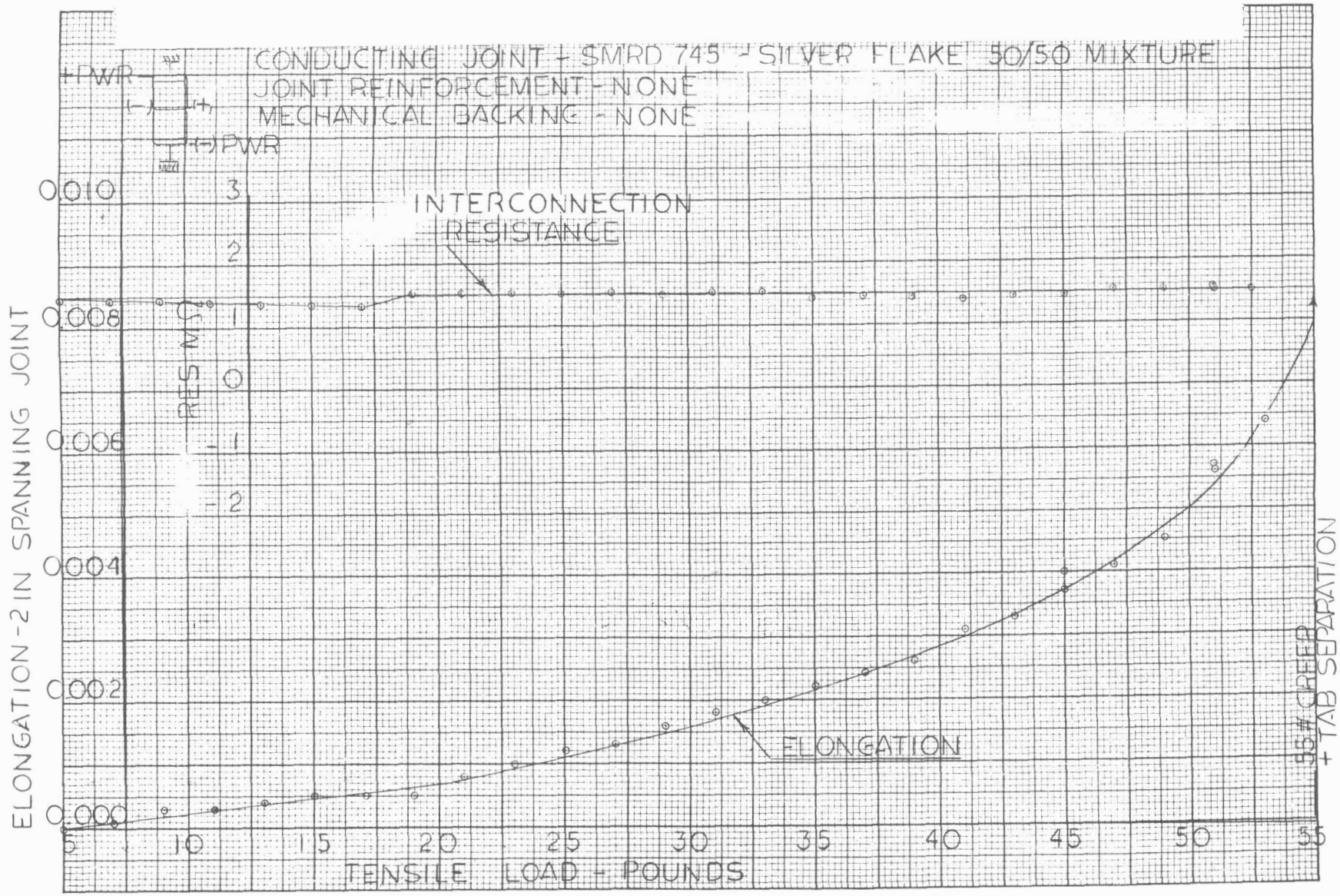


Figure A-3. Sample 46: Ultimate Tensile Test, Series (Y) Axis

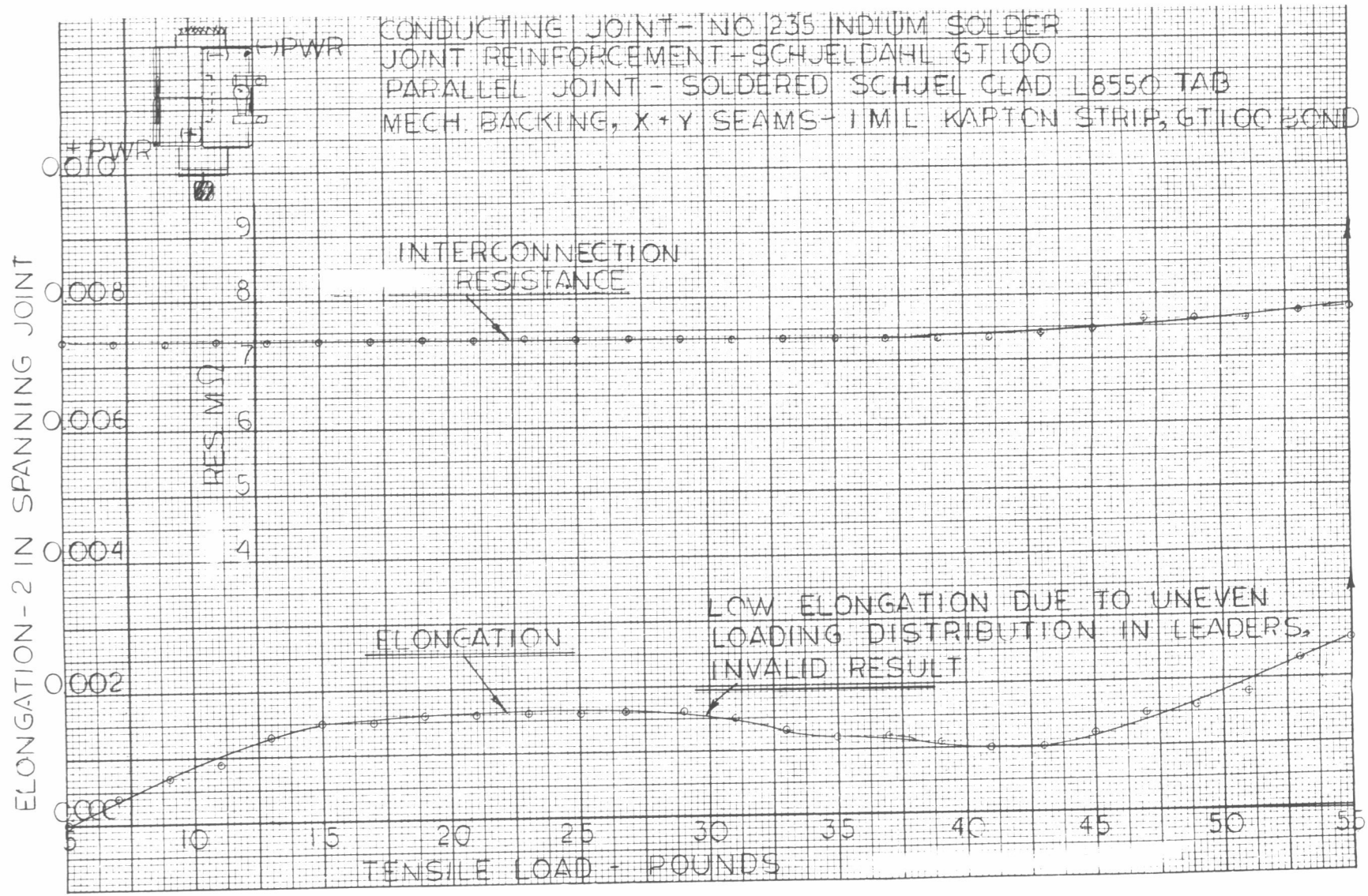


Figure A-4. Sample 32: Ultimate Tensile Test, Parallel (X) Axis

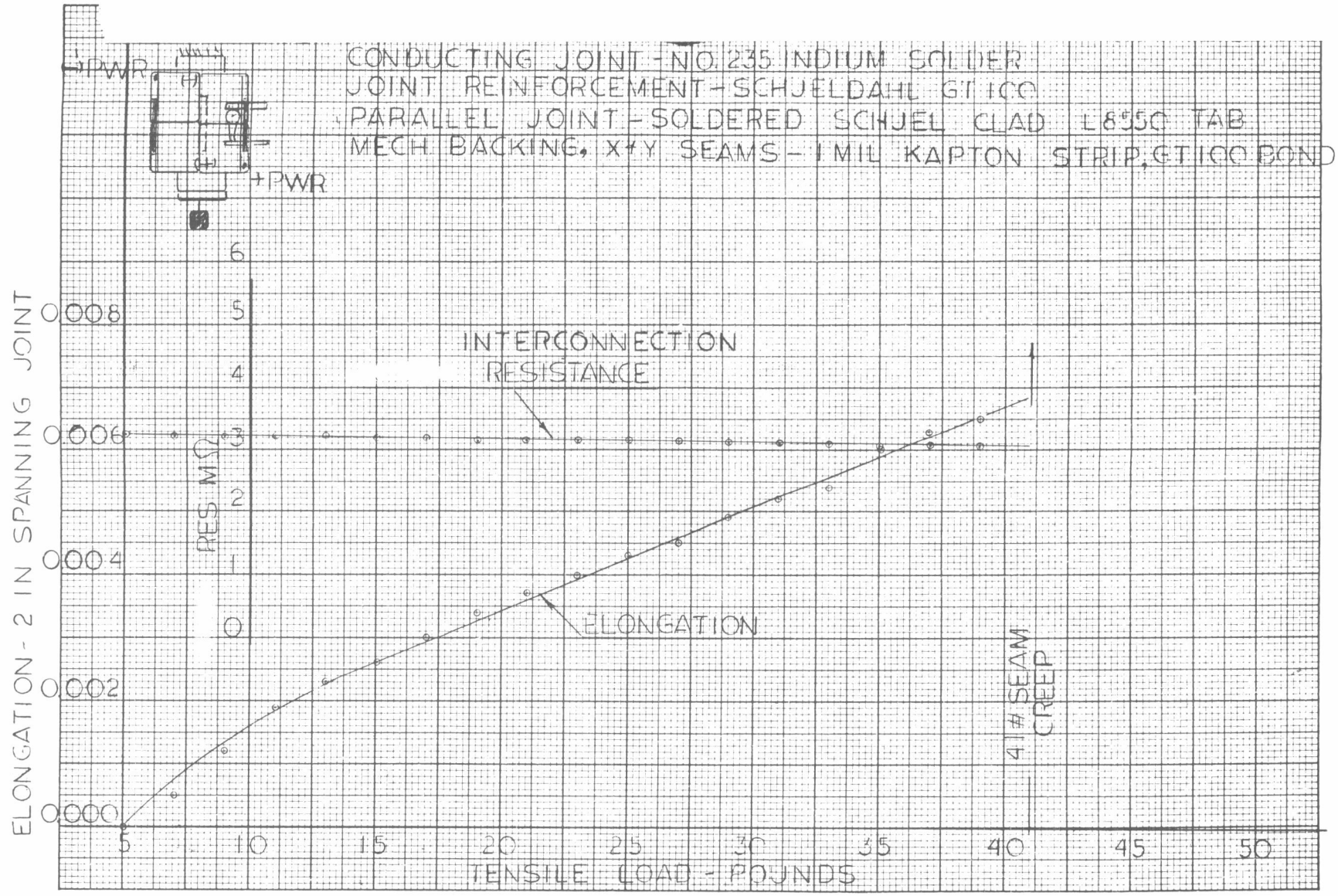


Figure A-5. Sample 48: Ultimate Tensile Test, Parallel (X) Axis

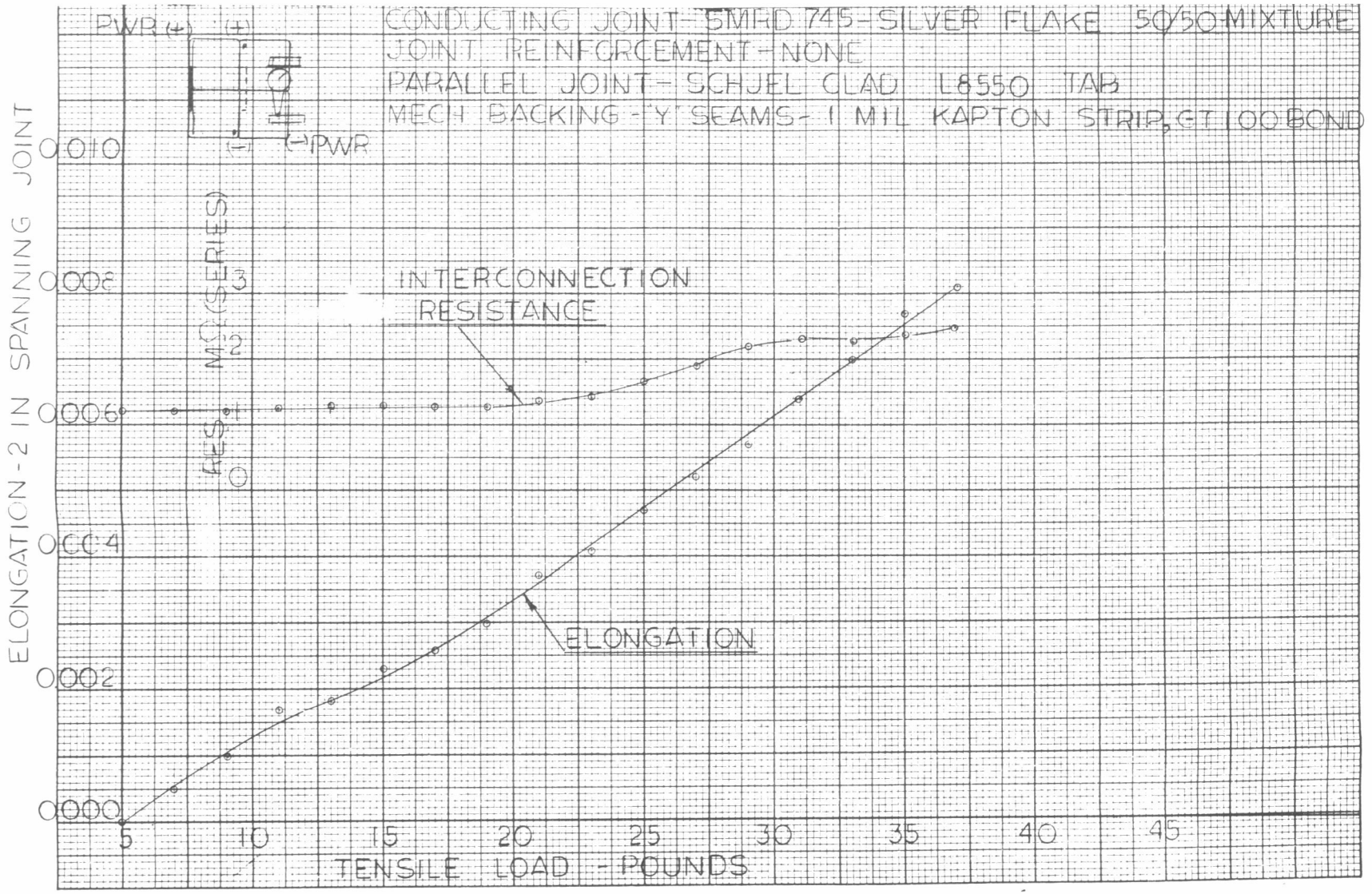


Figure A-6. Sample 49: Ultimate Tensile Test, Parallel (X) Axis

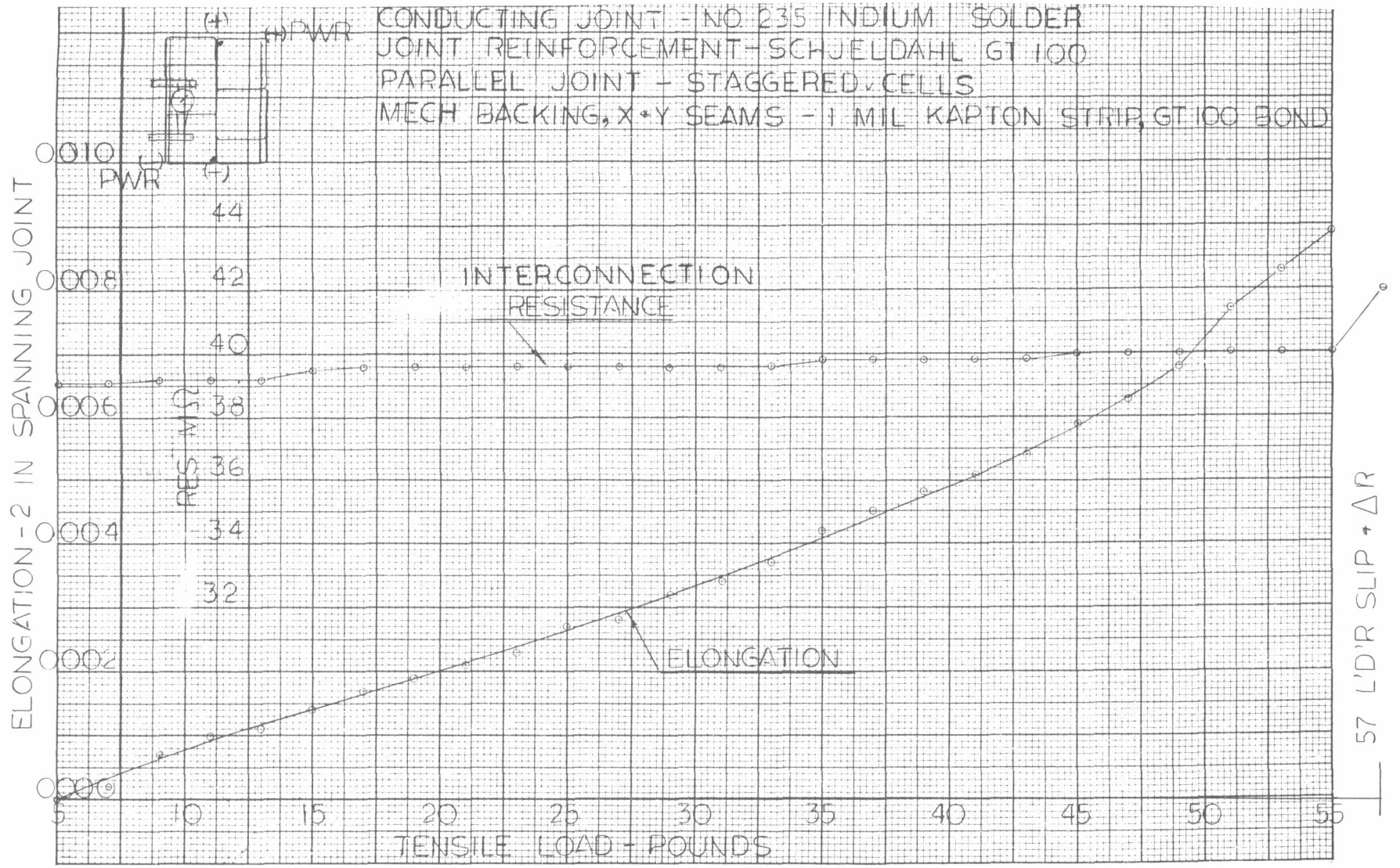


Figure A-7. Sample 28: Ultimate Tensile Test, Parallel (X) Axis

Table A-1. Series Interconnection Resistance Testing - 16-mm-Wide Cell Segments

Sample No.	Joining Method***	Millivolt Drop In Joint	Current Amps	Observed Resistivity 16 mm Wide Joint, Milliohms	Extrapolated Resistivity For Full Width (72.2 nm) Milliohms
1	1	6.00	1.0	6.00	1.33
2	1	5.15	1.0	5.15	1.14
3	1	8.74	1.0	8.74	1.94
Avg, 1,2,3*	1	6.63	1.0	6.63	1.47
4	3	7.96	0.5	15.92	3.53
5	3	8.85	0.5	17.70	3.92
6	3	9.19	1.0	9.19	2.04
7	3	9.57	0.70	13.67	3.03
Avg, 4,5,6,7*	3	n/a	n/a	14.12	3.13
8	2	0.42	0.75	0.56	0.12
9	2	8.99	1.0	8.99	1.99
10	2	1.41	1.0	1.41	0.32
11	2	7.75	1.0	7.75	1.72
Avg, 8,9,10,11*	2	n/a	n/a	4.68	1.04
12	2	0.89	1.0	0.89	0.20
13	2	1.75	1.0	1.75	0.39
Avg, 12,13**	2	1.32	1.0	1.32	0.29

*Clevite Plastic Substrate Cells

**Harshaw Molybdenum Substrate Cells (Mechanical Samples)

***Joining Methods

1. Soldered Indium, (156°C T Melt)
2. Soldered Indium Bismuth No. 235 Alloy (151°C T Melt)
3. Conductive Epoxy Bond, EP 3026

Table A-2. Ultimate Tensile Test Results - Experimental Joints

Sample No., Type	Highest Loaded Stable Point			Failure Point Load	Comments
	Load	Joint Resistance	Elongation		
	Pounds	Milliohms	Inches in 2 Inches	Pounds	
16, Clevite Cells #235 In-Bi Solder GT 100-Reinforced Butt Joint	19	0.48	(not measured)	20	Failure of leader bond distorted joint loading prior to failure.
17, Clevite Cells #235 In-Bi Solder GT 100-Reinforced Butt Joint	19	0.37	0.0020	*	*Leader peel started by 19#. Load removed & re-applied gradually. Failure on reload at 13#.
18, Harshaw Cells #235 In-Bi Solder GT 100-Reinforced Butt Joint	29	0.08	0.0015	30	Leader tear, joint still functional.
(Leader practice changed to provide both front and back surface shear loading)					
19, Clevite Cells #3026 Cond. Epoxy Butt Joint	24	(0.25)* 0.14	0.0055	25	Failure of both GT 100 fold back bond and conductive epoxy bond.
20, Clevite Cells SMRD 745-50% Ag Butt Joint	29	(0.77) 0.20	0.0040	30	Partial peel, partial tear of cell tab.
22, Clevite Cells SMRD 745-50% Ag Common Substrate	42	(1.31)	0.0065	43	Yield relief of App. 0.080 inch. Continuity maintained, R=1.65 milliohms.

*Parenthetical data measured on same side of cell
(Other resistance data measured across cell in parallel direction and across joint in series)

Table A-3. Roll Test Data - Sample 38 (Observed)

Sample 38 Single row of five cells in series - joints by Indium 235 solder, reinforced by GT 100; backing reinforcement 5/8-inch-wide strip of 1-mil Kapton bonded with GT 100

Primary Roll Test - 100 cycles back and forth over 2-inch-diameter drum while under 5 pounds tension

Note: Each of the four interconnection joints was monitored by taps to the positive and negative tabs located on opposite sides of the cell. The monitored voltage drop can be negative if the drop in the parallel direction in the tab is greater than the series drop. This condition was found in both the first five cell samples.

Condition	Joint No. 1 R, m ohms	Joint No. 2 R, m ohms	Joint No. 3 R, m ohms	Joint No. 4 R, m ohms
Initial	0.44	0.80	0.66	-1.92
10 cycles	0.50	0.80	0.58	-3.32
20 cycles	0.46	0.76	0.50	-3.10
30 cycles	0.50	0.76	0.42	-4.50
40 cycles	0.44	0.76	0.42	-3.96
50 cycles	0.46	0.76	0.40	-4.18
60 cycles	0.44	0.76	0.40	-1.60
70 cycles	0.40	0.76	0.40	-1.50
80 cycles	0.44	0.74	0.40	-1.40
90 cycles	0.40	0.72	0.40	-1.40
100 cycles	0.40	0.72	0.38	-1.68
Post 16 hours Steady 5 lb Load Dwell	0.40	0.74	-0.25	+0.25 to -2.0

Note: The variations in joint No. 4 data are attributable to a poor instrumentation contact which could not be repaired without damaging the joint.

Table A-4. Roll Test Data - Sample 39 (Observed)

Sample 39 (duplicate of sample 38) single row of five cells in series-joints by Indium 235 solder, reinforced by GT 100; backing reinforcement by 5/8-inch-wide strip of 1-mil Kapton bonded with GT 100

Primary Roll Test - 100 cycles back and forth over 2-inch-diameter drum while under 5 pounds tension

Note: Each of the four interconnection joints was monitored by taps to the positive and negative tabs located on opposite sides of the cell. The monitored voltage drop can be negative if the drop in the parallel direction in the tab is greater than the series drop

Condition	Joint No. 1 R, m ohms	Joint No. 2 R, m ohms	Joint No. 3 R, m ohms	Joint No. 4 R, m ohms
Initial	-0.50	0.00	1.36	0.04
10 cycles	-0.46	0.00	1.42	0.04
20 cycles	-0.50	0.00	1.60	0.04
30 cycles	-0.50	0.00	1.72	0.04
40 cycles	-0.50	0.02	1.78	0.08
50 cycles	-0.52	0.02	1.80	0.12
60 cycles	-0.52	0.04	1.80	0.10
70 cycles	-0.52	0.04	1.82	0.10
80 cycles	-0.52	0.04	1.82	0.10
90 cycles	-0.52	0.04	1.80	0.10
100 cycles	-0.52	0.04	1.80	0.10
Post 16 hours Steady 5 lb Load Dwell	-0.42	0.04	0.60*	0.08

*Data appeared to be temperature dependent; voltage drop was slowly climbing. Same trend was evident in prior days testing per new - 50 cycle data.

Table A-5. Roll Test Data - Sample 40 (Observed)

Sample 40 Single row of five cells in series - joints by 50% Ag filled SMRD 745 Adhesive

Primary Roll Test - 100 cycles back and forth over 2-inch-diameter drum while under 5 pounds tension

Note: Each of the four interconnection joints was monitored by taps to the positive and negative tabs located on opposite sides of the cell. The monitored voltage drop can be negative if the drop in the parallel direction in the tab is greater than the series direction drop

Condition	Joint No. 1 R, m ohms	Joint No. 2 R, m ohms	Joint No. 3 R, m ohms	Joint No. 4 R, m ohms
Initial	0.14	0.02	-0.10	0.94
10 cycles	0.04	0.02	0.0	0.98
20 cycles	0.14	0.04	-0.04	1.04
30 cycles	0.14	0.04	0.0	1.08
40 cycles	0.14	0.04	0.0	1.08
50 cycles	0.20	0.04	0.0	1.08
60 cycles	0.22	0.04	0.02	1.10
70 cycles	0.22	0.04	0.04	1.12
80 cycles	0.20	0.04	0.0	1.14
90 cycles	0.22	0.04	0.02	1.16
100 cycles	0.22	0.04	0.04	1.18

Table A-6. Roll Test Data - Sample 41 (Observed)

Sample 41 - (duplicate of sample 40) Single row of five cells in series-joints by 50% Ag filled SMRD 745 Adhesive

Primary Roll Test - 100 cycles back and forth over 2-inch-diameter drum while under 5 pounds tension

Note: Each of the four interconnection joints was monitored by taps to the positive and negative tabs located on opposite sides of the cell. The monitored voltage drop can be negative if the drop in the parallel direction in the tab is greater than the series direction drop.

Condition	Joint No. 1 R, m ohms	Joint No. 2 R, m ohms	Joint No. 3 R, m ohms	Joint No. 4 R, m ohms
Initial	-1.08	1.86	0.80	1.00
10 cycles	-1.10	1.86	0.82	1.08
20 cycles	-1.10	1.82	0.84	1.10
30 cycles	-1.10	1.80	0.86	1.08
40 cycles	-1.10	1.80	0.86	1.08
50 cycles	-1.10	1.82	0.86	1.06
60 cycles	-1.10	1.84	0.88	1.06
70 cycles	-1.10	1.84	0.86	1.08
80 cycles	-1.10	1.84	0.88	1.08
90 cycles	-1.10	1.84	0.88	1.08
100 cycles	-1.10	1.84	0.90	1.08

Table A-7. Roll Test Results - Sample 42 (Observed)

Sample 42 - "Staggered" 2 1/2 parallel x 5 series Joined by Indium No. 235 solder Reinforcement in Joint by GT 100, Fold Back and backing strip bonded by GT 100

Primary Roll Test

Condition	Joint No. 1 R, m ohms	Joint No. 3 R, m ohms	Joint No. 4 R, m ohms
Initial	8.72	-1.80	14.68
10 cycles	8.80	-1.88	14.80
20 cycles	8.80	-1.80	14.88
30 cycles	8.80	-1.84	15.36
40 cycles	8.80	-1.84	15.36
50 cycles	8.80	-1.84	15.36
60 cycles	8.80	-1.84	15.40
70 cycles	8.80	-1.84	15.40
80 cycles	8.80	-1.84	15.44
90 cycles	8.76	-1.88	15.44
100 cycles	8.76	-1.88	15.44

Secondary Roll Test

Condition	Joint No. 1 R, m ohms	Joint No. 2 R, m ohms	Joint No. 3 R, m ohms	Joint No. 4 R, m ohms
Pre test	8.60	-17.76	-3.20	14.20
10 cycles	8.88	-17.72	-3.20	14.40
20 cycles	8.92	-17.92	-3.12	14.60
30 cycles	8.96	-18.20	-3.08	14.68
40 cycles	8.92	-18.32	-3.12	14.76
50 cycles	8.96	-18.72	-3.08	14.88
60 cycles	9.00	-18.68	-3.08	14.96
70 cycles	9.00	-19.24	-3.12	15.20
80 cycles	9.00	-19.68	-2.88	15.28
90 cycles	9.00	-19.80	-2.88	15.28
100 cycles	9.00	-19.80	-2.88	15.28

Table A-8. Roll Test Results - Sample 43 (Observed)

Sample 43 - "Schjel Clad Tab" 2 parallel x 5 series Joined by Indium No. 235 Solder, Reinforcement in the joint by GT 100, Fold Back and backing strip bonded by GT 100

Primary Roll Test

Condition	Joint No. 1 R, m ohms	Joint No. 3 R, m ohms	Joint No. 4 R, m ohms
New	2.76	-0.54	2.28
10 cycles	2.52	-0.50	2.24
20 cycles	2.50	-0.50	2.24
30 cycles	2.50	-0.48	2.24
40 cycles	2.50	-0.50	2.24
50 cycles	2.50	-0.50	2.24
60 cycles	2.48	-0.48	2.24
70 cycles	2.50	-0.48	2.24
80 cycles	2.50	-0.50	2.24
90 cycles	2.46	-0.50	2.26
100 cycles	2.50	-0.46	2.24

Secondary Roll Test				
Condition	Joint No. 1 R (mohms)	Joint No. 2 R (mohms)	Joint No. 3 R (mohms)	Joint No. 4 R (mohms)
Post Primary, Pre Secondary	3.18	-4.32	-0.40	2.12
10 cycles	3.28	-4.50	-0.40	2.12
20 cycles	3.20	-4.42	-0.40	1.96
30 cycles	3.18	-4.42	-0.38	1.96
40 cycles	3.18	-4.42	-0.38	1.92
50 cycles	3.18	-4.40	-0.38	1.92
60 cycles	3.18	-4.40	-0.38	1.92
70 cycles	3.28	-4.50	-0.38	2.02
80 cycles	3.30	-4.50	-0.40	1.96
90 cycles	3.30	-4.50	-0.40	1.96
100 cycles	3.30	-4.50	-0.38	1.96

Table A-9. Roll Test Results - Sample 44 (Observed)

Sample 44: 2 Parallel x 5 Series, "Schjel Clad Tab" Parallel Connection, Joined by Indium No. 235 Solder, Joint Reinforcement by GT100, Series Joint and Parallel Seams Backed by 1-Mil Kapton, GT100 Bonded

Primary Roll Test*				
Condition	Joint No. 1 R (mohms)	Joint No. 2 R (mohms)	Joint No. 3 R (mohms)	Joint No. 4 R (mohms)
Initial	-1.0	-0.98	-1.60	0.90
10 cycles	-0.78	-0.88	-1.94	0.38
20 cycles	-0.78	-0.88	-1.98	0.34
30 cycles	-0.78	-0.84	-2.04	0.38
40 cycles	-0.76	-0.84	-2.04	0.34
50 cycles	-0.76	-0.84	-2.04	0.32
60 cycles	-0.78	-0.84	-2.04	0.32
70 cycles	-0.78	-0.84	-2.04	0.30
80 cycles	-0.76	-0.80	-2.06	0.38
90 cycles	-0.78	-0.80	-2.06	0.32
100 cycles	-0.78	-0.78	-2.10	0.32
After 72 hours with 5 pounds steady tension				
	-0.78	-0.90	-1.50	0.10

Secondary Roll Test				
Condition	Joint No. 1 R (mohms)	Joint No. 2 R (mohms)	Joint No. 3 R (mohms)	Joint No. 4 R (mohms)
Post Primary Pre Secondary	-0.72	-1.32	-1.64	0.78
10 cycles	-0.72	-1.32	-1.66	0.78
20 cycles	-0.76	-1.30	-1.68	0.78
25 cycles	Leader broke, snapping module to floor and severely flexing it			
25 cycles	-0.44	-1.52	-1.50	0.32
30 cycles	-0.48	-1.50	-1.54	0.28
40 cycles	-0.54	-1.46	-1.58	0.28
50 cycles	-0.61	-1.36	-1.62	0.30
60 cycles	-0.61	-1.36	-1.64	0.30
70 cycles	-0.61	-1.36	-1.64	0.30
80 cycles	-0.61	-1.32	-1.64	0.32
90 cycles	-0.64	-1.32	-1.64	0.32
100 cycles	-0.70	-1.30	-1.66	0.34

Table A-10. Roll Test Results - Sample 44 (Observed)

Sample 47: 2-1/2 Parallel x 5 Series, "Staggered" Parallel Connection, Joined by Indium No. 235 Solder, Joint Reinforcement by GT 100, Series Joint and Parallel Seams Backed by 1-Mil Kapton, GT 100 Bonded

Primary Roll Test				
Condition	Joint No. 1 R (mohms)	Joint No. 2 R (mohms)	Joint No. 3 R (mohms)	Joint No. 4 R (mohms)
Initial	11.20	9.84	-0.59	-4.70
10 cycles	10.84	0.70	+7.30	-5.30
20 cycles	12.00	1.46	6.40	-5.48
30 cycles	11.70	0.70	6.80	-5.66
40 cycles	12.10	0.64	6.90	-5.76
50 cycles	12.20	0.60	6.96	-5.82
60 cycles	12.24	0.60	7.00	-5.92
70 cycles	12.28	0.60	7.04	-6.08
80 cycles	12.32	0.54	7.10	-6.06
90 cycles	12.08	0.42	7.20	-6.20
100 cycles	12.10	0.40	7.21	-6.24
Secondary Roll Test				
Condition	Joint No. 1 R (mohms)	Joint No. 2 R (mohms)	Joint No. 3 R (mohms)	Joint No. 4 R (mohms)
Post Primary Pre Secondary	11.70	-1.86	8.40	-5.46
10 cycles	11.50	-1.24	7.74	-5.68
20 cycles	11.54	-1.34	7.84	-5.88
30 cycles	11.68	-1.32	8.00	-6.02
40 cycles	11.52	-1.34	7.94	-6.12
50 cycles	11.68	-1.36	8.10	-6.28
60 cycles	11.60	-1.20	8.10	-6.32
70 cycles	11.50	-1.32	8.14	-6.40
80 cycles	11.36	-1.28	7.82	-6.46
90 cycles	11.38	-1.20	8.08	-6.50
100 cycles	11.48	-1.28	8.02	-6.52

Table A-11. Summary of End Point Results: Ultimate Tensile Tests

Sample	Configuration	Loading Direction	Final Load, Pounds	Termination Cause	Elongation, In./2-In. Span	Joint Resistance, Milliohms
35	1x2 Soldered	Series	43	Bond creep	0.0124 (41 lb)	-0.30 (5 lb) -0.24 (41 lb)
36	1x2 Soldered	Series	49	Leader loosen	0.0100 (49 lb)	0.42 (5 lb) 0.70 (49 lb)
46	1x2 SMRD 745+Ag	Series	55	Creep, end tab open	0.0064 (53 lb)	1.46 (5 lb) 1.50 (53 lb)
32	2x2 Soldered Schjel Clad Tab	Parallel	55	Creep	0.0026 (55 lb) *	7.38 (5 lb) 7.74 (55 lb)
48	2x2 Soldered Schjel Clad Tab	Parallel	41	Creep of seam tape bond	0.0065 (39 lb)	3.22 (5 lb) 3.08 (39 lb)
49	2x2 SMRD 745+Ag Schjel Clad Tab	Parallel	39	Large resist-ance change	0.0081 (37 lb)	1.2 (5 lb) 2.48 (37 lb)
28	$2\frac{1}{2}$ x2 Soldered Staggered Cells	Parallel	57	Loading shift from clamp slip caused electrical resistance instability	0.0089 (55 lb)	39.1 (5 lb) 42.0 (57 lb)

*Low elongation due to uneven loading distribution in leaders - invalid result.

Table A-12. Summary of End Point Results of Ultimate Tensile Tests

Following Roll Test

Sample	Configuration	Loading Direction	Final Load (pounds)	Termination Cause	Elongation (In./2 in. span)	No. 1 Joint Resistance (milliohms)	No. 2 Joint Resistance (milliohms)	No. 3 Joint Resistance (milliohms)	No. 4 Joint Resistance (milliohms)
38	1 x 5 Soldered	Series	23*	Failure of Joint 4	0.0025 (21 lb)	0.40 (5 lb) 0.42 (21 lb)	0.72 (5 lb) 0.72 (21 lb)	-0.60 (5 lb) +3.74 (21 lb)	(No data, inst. tab contact opened)
55	1 x 5 Soldered	Series	35	Creep, Joint 2	0.0050 (33 lb)	1.02 (5 lb) 1.16 (33 lb)	1.06 (5 lb) 0.98 (33 lb)	0.18 (5 lb) 0.22 (33 lb)	2.38 (5 lb) 2.32 (33 lb)
40	1 x 5 SMRD 745 + Ag	Series	57	Joint 4, increased Resistance steadily	0.0118 (55 lb)	0.24 (5 lb) -0.72 (55 lb)	-0.24 (5 lb) +0.26 (55 lb)	-0.40 (5 lb) -0.60 (55 lb)	1.38 (5 lb) 4.20 (55 lb)
42	2-1/2 x 5 Soldered "Staggered"	Series	67	Corner of Joint backing tape lifting	0.0024 (67 lb)	8.68 (5 lb) 9.24 (67 lb)	-17.80 (5 lb) -16.56 (67 lb)	-4.24 (5 lb) -4.08 (67 lb)	15.52 (5 lb) 15.56 (67 lb)
43	2 x 5 Soldered	Series	59	Joint 1, parted	0.0047 (57 lb)	2.98 (5 lb) 3.16 (57 lb)	-4.54 (5 lb) -4.60 (57 lb)	-0.42 (5 lb) -0.40 (57 lb)	2.28 (5 lb) 2.12 (57 lb)
51	2 x 5 SMRD 745 + Ag	Series	87	Loading hook straighten joint still good	0.0037 (85 lb)	4.40 (5 lb) 5.04 (85 lb)	0.64 (5 lb) 0.40 (85 lb)	0.80 (5 lb) 0.66 (85 lb)	-4.14 (5 lb) -4.10 (85 lb)
52	5 x 2 SMRD 745 + Ag	Parallel	33	Off Scale (-) resistance change	0.0024 (33 lb)	-4.40 (5 lb) -8.40 (31 lb)	N/A	N/A	N/A
53	5 x 2 Soldered	Parallel	55	Joint 1 parted	0.0051 (55 lb)	134 (5 lb)** 62.4 (9 lb) 39.2 (33 lb) 105.2 (35 lb) 120.4 (53 lb)	N/A	N/A	N/A
54	5 x 2 Soldered	Parallel	65	Off Scale (-) Resistance change	0.0073 (65 lb)	3.56 (5 lb) 8.60 (23 lb) 2.00 (33 lb) 12.00 (43 lb) 5.20 (63 lb)	N/A	N/A	N/A

*GT 100 in this unit was from the 0.25 in. width overaged roll
**Suspect loosened silver-Kapton bond from roll test

Table A-13. Data Taken During Thermal Cycling Test Sample No. 45, 2 Series x 3 Parallel CdS Cells, 5-Pound Tensile Load Both Axes

		Cycle 1	Cycle 6	Cycle 12	Cycle 18	Cycle 24
Temperature ^{O}F		105	120	120	120	118
Open Circuit V		0.745	0.735	0.748	0.732	0.741
1.0 AMP	V	0.650	0.655	0.662	0.658	0.648
	W	0.65	0.655	0.662	0.658	0.648
	EFF	0.0212	0.0214	0.0216	0.0214	0.0211
1.2 AMP	V	0.614	0.620	0.621	0.618	0.607
	W	0.7368	0.7440	0.7452	0.7416	0.7284
	EFF	0.0240	0.0243	0.0243	0.0242	0.0237
1.3 AMP	V	0.589	0.596	0.595	0.589	0.580
	W	0.7657	0.7748	0.7735	0.7657	0.7540
	EFF	0.0250	0.0253	0.0252	0.0250	0.0246
1.4 AMP	V	0.560	0.567	0.561	0.551	0.545
	W	0.7840	0.7938	0.7854	0.7714	0.7630
	EFF	0.0256	0.0259	0.0256	0.0251	0.0249
1.5 AMP	V	0.516	0.518	0.513	0.490	0.490
	W	0.7740	0.7770	0.7695	0.7350	0.7350
	EFF	0.0252	0.0253	0.0251	0.0240	0.0240
1.6 AMP	V	0.458	0.440	0.447	0.397	0.406
	W	0.7328	0.7040	0.7152	0.6352	0.6496
	EFF	0.0239	0.0230	0.0233	0.0207	0.0212
Short Circuit Current, Amps		1.86	1.82	1.86	1.82	1.80

Table A-14. Transient Data Taken During Thermal Cycling Test Sample 45, 2 Series x 2 Parallel CdS Cells - 5 Pound Tensile Load Both Axes

	Cycle No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Module Power	-50°F I						1.26		1.24	1.24	1.24	1.22	1.23	1.18	1.22	1.22	1.22	1.22	1.23	1.07		1.23	1.22	1.21	
	-50°F V						0.89		0.895	0.89	0.89	0.872	0.89	0.86	0.888	0.88	0.88	0.88	0.888	0.892		0.887	0.890	0.865	
	0°F I		1.16			1.16		1.11	1.14		1.14		1.12	1.10	1.12	1.12	1.12	1.12	1.13	0.99	1.12	1.13	1.12	1.12	1.13
	0°F V		0.74			0.77		0.725	0.760		0.76		0.752	0.750	0.745	0.745	0.737	0.739	0.750	0.766	0.738	0.748	0.748	0.744	0.735
	+50°F I				1.09							1.09		1.06	1.07	1.07	1.07	1.06	1.07	0.94				1.07	1.08
	+50°F V				0.675							0.682		0.686	0.675	0.670	0.670	0.665	0.670	0.701				0.638	0.664
	+100°F I			1.04			1.05	1.02	1.04	1.03	1.04	1.03	1.02	1.02	1.02	1.02	1.02	1.02	1.03	0.91	1.03	1.02	1.02	1.03	1.03
	+100°F V			0.615			0.635	0.655	0.635	0.628	0.635	0.630	0.625	0.640	0.620	0.615	0.610	0.615	0.62	0.669	0.612	0.612	0.609	0.621	0.617
	+131°F I	1.0	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.00	1.00	1.00	1.0	0.99	1.00	1.00	1.0	1.0	1.01	0.87	1.01	1.01	1.00	1.01	1.01
	+131°F V	0.56	0.57	0.58	0.595	0.60	0.595	0.603	0.607	0.605	0.608	0.603	0.605	0.610	0.599	0.592	0.590	0.594	0.602	0.619	0.595	0.600	0.593	0.600	0.593
Voltage Drop In Joint	-50°F MV						-0.7		-0.7	-0.8	-0.8	-0.7	-0.7	-0.9	-0.75	0.70	-0.70	-0.70	-0.70	-0.8	-0.7	-0.7	-0.7	-0.75	
	0°F MV		-2.10			-1.2		-1.7	-1.5		-1.55		-1.85	-1.85	-1.90	-1.80	-1.80	-1.85	-1.80	-1.80	-1.80	-1.80	-1.75	-1.90	-1.90
	+50°F MV				-1.80							-1.85		-1.85	-1.90	-1.80	-1.80	-1.80	-1.80	-1.85				-1.80	-1.83
	+100°F MV			-2.10			-1.80	-1.8	-1.8	-1.9	-1.9	-1.85	-1.90	-1.95	-1.95	-1.95	-1.90	-1.85	-1.85	-1.95	-1.90	-1.95	-1.85	-1.85	-1.90
	+131°F MV	-2.35	-2.35	-2.30	-2.0	-1.95	-2.10	-2.20	-2.10	-2.15	-2.25	-2.20	-2.10	-2.10	-2.10	-2.0	-2.0	-1.95	-1.95	-2.15	-1.95	-2.0	-2.0	-2.0	-2.0

		5-lb Tension in Series Direction Intensity = 147 mw/cm^2 per Silicon Cell Std.					
		Cycle 1	Cycle 6	Cycle 12	Cycle 18	Cycle 24	8
Temperature ^{o}F		140	140	135	135	135	1
Open Circuit Voltage		0.691	0.704	0.712	0.706	0.708	0.
1.0 Amp	Volts	0.602	0.605	0.614	0.608	0.595	0.
	Watts	0.602	0.605	0.614	0.608	0.595	0.
	Efficiency	1.86	1.87	1.90	1.88	1.84	1.
1.2 Amps	Volts	0.552	0.559	0.565	0.553	0.543	0.
	Watts	0.662	0.671	0.678	0.664	0.652	0.
	Efficiency	2.05	2.08	2.10	2.06	2.02	1.
1.3 Amps	Volts	0.519	0.529	0.534	0.517	0.505	0.
	Watts	0.675	0.688	0.694	0.672	0.656	0.
	Efficiency	2.09	2.13	2.15	2.08	2.03	1.
1.4 Amps	Volts	0.462	0.487	0.491	0.470	0.452	0.
	Watts	0.647	0.682	0.687	0.658	0.633	0.
	Efficiency	2.00	2.11	2.13	2.04	1.96	1.
1.5 Amps	Volts	0.382	0.419	0.427	0.398	0.374	0.
	Watts	0.573	0.628	0.640	0.597	0.561	0.
	Efficiency	1.77	1.95	1.98	1.85	1.74	0.
1.6 Amps	Volts	0.267	0.303	0.328	0.288	0.270	0.
	Watts	0.427	0.485	0.525	0.461	0.432	0.
	Efficiency	1.32	1.50	1.63	1.43	1.34	0.
I_{sc}		1.79	1.81	1.82	1.81	1.81	1.

FOLDOUT FRAME 1

Table A-15. Current Voltage Data: Sample 45 Thermal Vacuum Cycling and Dwell Tests with Series Only, Parallel Only, Biaxial Tension Loads

	5-lb Tension in Parallel Direction Intensity = 147 mw/cm^2 per Silicon Cell Std.						5-lb Tension, Biaxial 147 mw/cm^2 per Silicon Std.	
Hrs	Cycle 1	Cycle 6	Cycle 12	Cycle 18	Cycle 24	8 Hrs	6 Hrs	8 Hrs
41	144	135	137	137	140	135	132	(T' couple Out)
700	0.718	0.725	0.724	0.725	0.712	0.705	0.720	0.720
535	0.579	0.602	0.598	0.600	0.582	0.535	0.573	0.555
535	0.579	0.602	0.598	0.600	0.582	0.535	0.573	0.555
36	1.79	1.87	1.85	1.86	1.80	1.66	1.78	1.72
446	0.524	0.542	0.533	0.537	0.504	0.449	0.483	0.485
535	0.629	0.650	0.640	0.644	0.605	0.539	0.580	0.582
36	1.95	2.01	1.98	1.99	1.87	1.67	1.80	1.80
382	0.480	0.490	0.490	0.487	0.448	0.385	0.421	0.435
497	0.624	0.637	0.637	0.633	0.582	0.500	0.547	0.565
54	1.93	1.97	1.97	1.96	1.80	1.55	1.69	1.75
298	0.422	0.426	0.430	0.424	0.375	0.305	0.342	0.370
417	0.591	0.596	0.602	0.594	0.525	0.427	0.479	0.518
29	1.83	1.85	1.86	1.84	1.63	1.32	1.48	1.60
200	0.344	0.338	0.350	0.339	0.288	0.207	0.248	0.280
300	0.516	0.507	0.525	0.508	0.432	0.310	0.372	0.420
93	1.60	1.57	1.63	1.57	1.34	0.96	1.15	1.30
.03	0.243	0.240	0.245	0.245	0.192	0.104	0.155	0.179
.65	0.389	0.384	0.392	0.392	0.307	0.166	0.248	0.286
51	1.20	1.19	1.21	1.21	0.95	0.51	0.77	0.89
71	1.83	1.84	1.83	1.86	1.80	1.70	1.76	1.78

FOLDOUT FRAME 2

1

Table A-16. Current-Voltage Data: 5 Pound Tension-Series Direction Sample 50, 2 Parallel x 2 Series, SMRD 745 + Ag Flake; Schel Clad Tab Paralleling; Intensity = 158 mw/cm^2 Per Silicon Standard

		Cycle 1	Cycle 6	Cycle 12	Cycle 18	Cycle 24	4 Hr Dwell	8 Hr Dwell +1 Cycle
Temperature	°F	130	130	131	128	125	135	127
Open Circuit Voltage		0.746	0.761	0.747	0.750	0.748	0.722	0.740
1.0 Amp	Volts	0.640	0.660	0.649	0.652	0.643	0.604	0.612
	Watts	0.640	0.660	0.649	0.652	0.643	0.604	0.612
	Eff (%)	1.847	1.905	1.873	1.882	1.856	1.743	1.766
1.2 amp	Volts	0.601	0.622	0.613	0.610	0.602	0.560	0.558
	Watts	0.721	0.746	0.736	0.732	0.722	0.672	0.670
	Eff (%)	2.081	2.153	2.124	2.112	2.084	1.939	1.933
1.3 amp	Volts	0.575	0.596	0.589	0.582	0.575	0.513	0.521
	Watts	0.747	0.775	0.766	0.757	0.747	0.667	0.677
	Eff (%)	2.156	2.237	2.211	2.185	2.156	1.925	1.954
1.4 amp	Volts	0.544	0.562	0.557	0.547	0.543	0.467	0.463
	Watts	0.762	0.787	0.780	0.766	0.760	0.654	0.648
	Eff (%)	2.199	2.271	2.250	2.211	2.193	1.887	1.870
1.5 amp	Volts	0.496	0.507	0.511	0.500	0.498	0.388	0.375
	Watts	0.744	0.760	0.766	0.750	0.747	0.582	0.562
	Eff (%)	2.147	2.193	2.211	2.164	2.156	1.680	1.622
1.6 amp	Volts	0.402	404	0.430	0.418	0.410	0.214	0.238
	Watts	0.643	0.646	0.688	0.669	0.656	0.342	0.381
	Eff (%)	1.855	1.864	1.985	1.931	1.893	0.987	1.099
Short Circuit Current Amps		1.80	1.78	1.79	1.79	1.78	1.710	1.760

APPENDIX B

SOLAR SIMULATOR CHECKOUT AND CALIBRATION

Figure B-1 shows the newly completed solar simulator - vacuum chamber test installation during operation. The test module is suspended across the lower section of the vacuum chamber with cold wall views to both the front and back of the cell. Figure B-2 and B-3 show the major elements of the test equipment, the carbon arc illumination source, with its iris intensity control, and the vacuum chamber with the top-mounted mirror which directs the light beam downward onto the test plane.

Figure B-1. Solar Simulator-Vacuum Chamber Test Installation for Thermal Cycling Test of CdS Solar Cell Modules

Initial light field adjustment was made by positioning of the arc, the mirror, and the electrodes within the arc. Uniformity was progressively improved from the initial +11.5%, -10.3% finally reaching a span of +5.7%, -3.7% from the average of the nine cells distributed

Figure B-2. Carbon Arc Solar Illumination Source for CdS Solar Cell Module Test

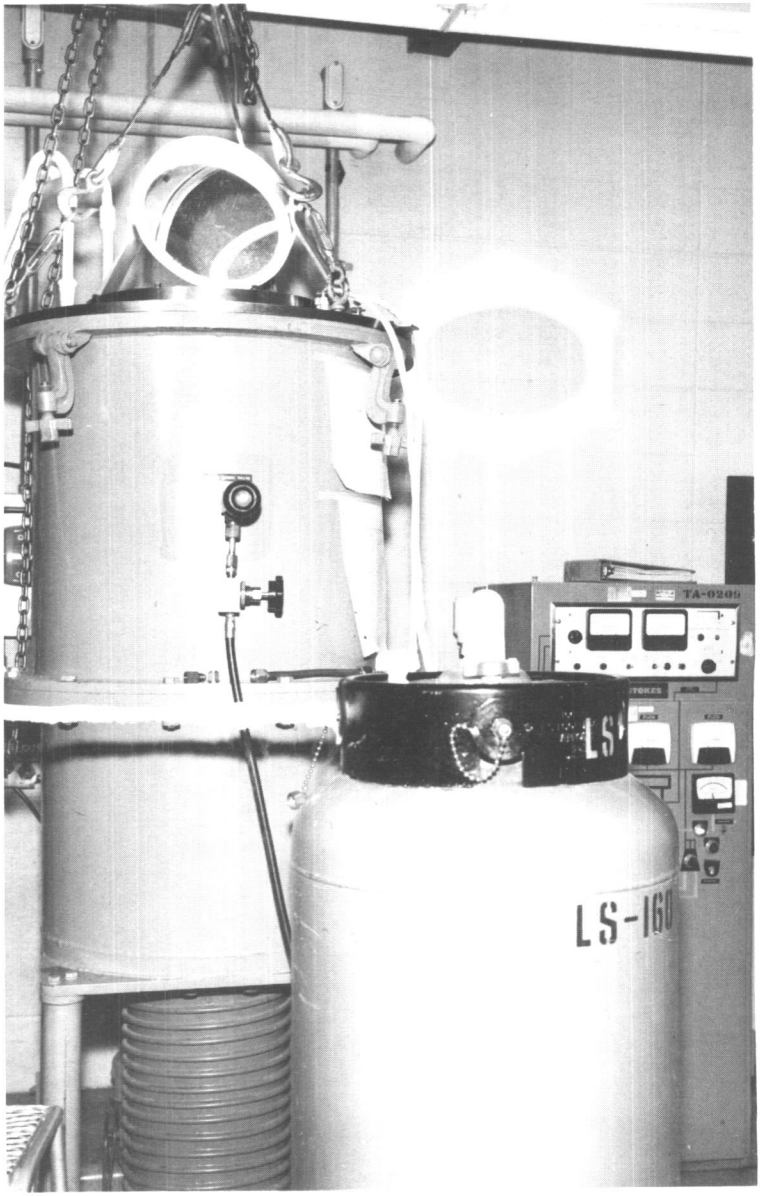


Figure B-3. Thermal Cycling Vacuum Chamber with Top-Mounted Mirror and Liquid Nitrogen Supply for Cold Walls

throughout the test plane. The nine-cell uniformity monitoring module is shown in Figure B-4 mounted on the Vacuum Thermal Cycling Test Plane fixture. Figure B-5 show the Chamber top cover with the liquid nitrogen cooled wall installed just prior to insertion of the test plane fixture.

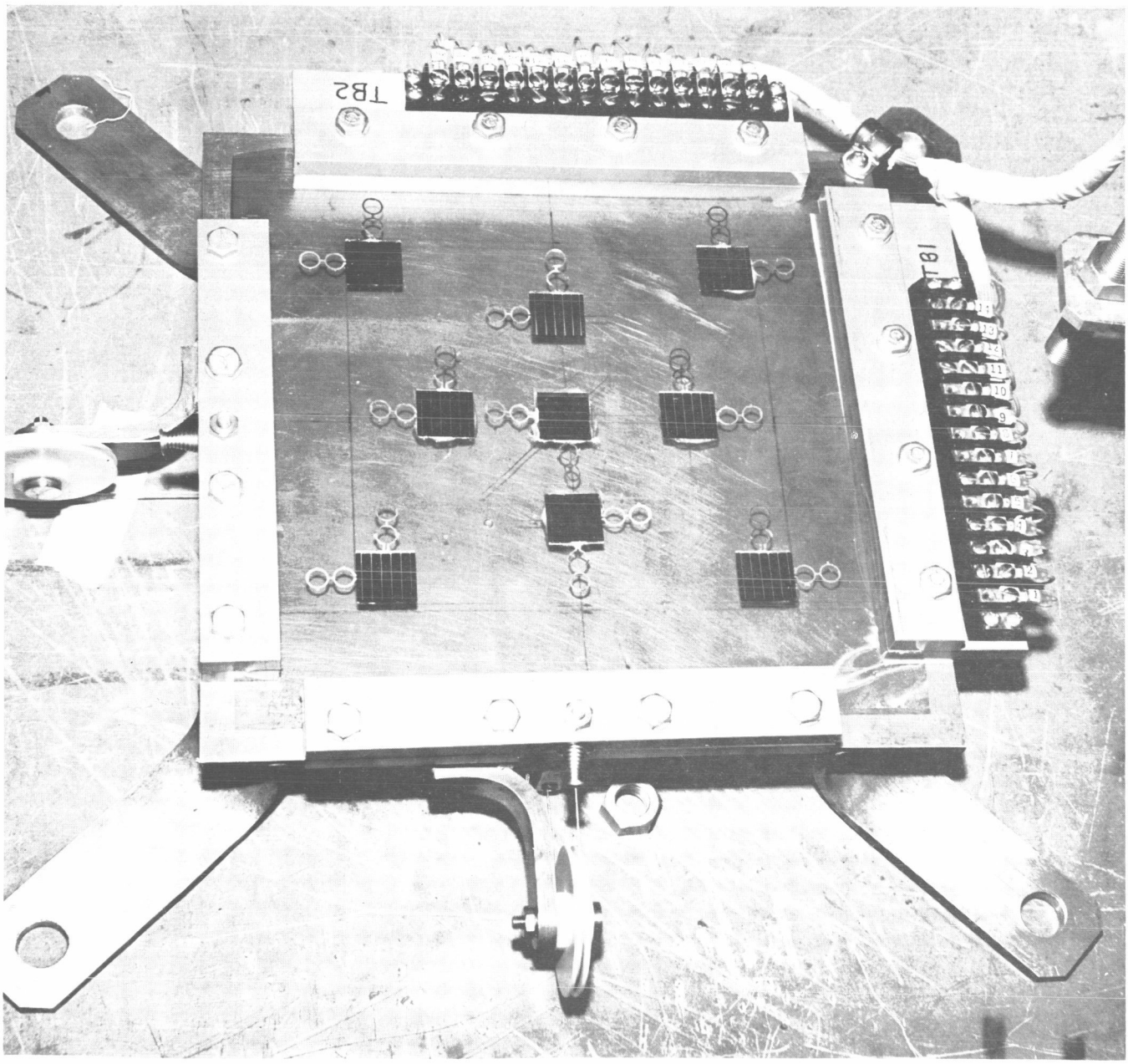


Figure B-4. Test Specimen Holder with a Nine-cell Light Intensity and Distribution Module Installed

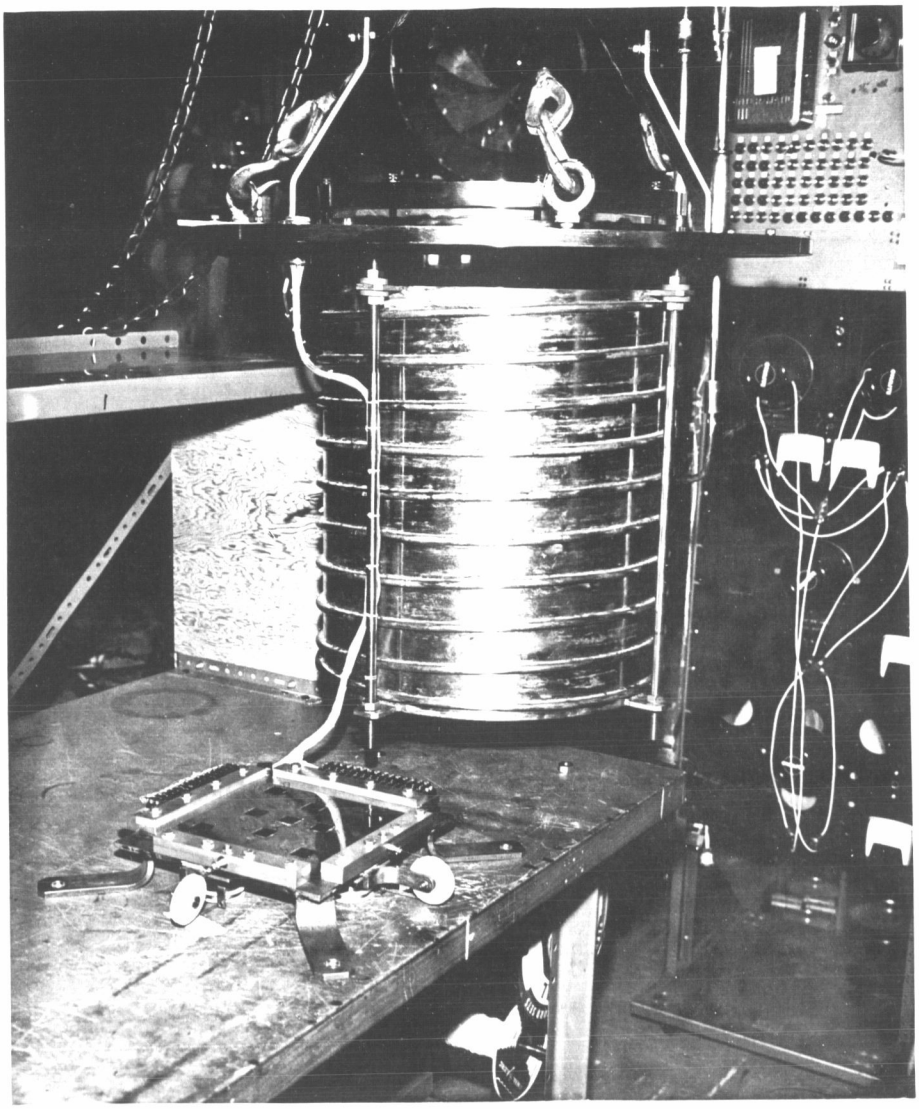


Figure B-5. Cold Cylinder and Test Specimen Holder Attached to Cycle Test Chamber Cover

Intensity level can be varied without upsetting the uniformity by use of the iris control. Due to the variation in light levels between successive carbon rods, it was determined that silicon cell monitor cells would be required in order to set the light level during the CdS module tests.

The ability of the walls to bring the temperature of the test plane down to the required -70°C (-94°F) was demonstrated, as was the ability of the chamber to reach the 1×10^{-6} mm Hg vacuum level.

APPENDIX C

SOLDER BONDING MACHINE 47J212158 AND ASSEMBLY FIXTURE 47J212156

C.1 GENERAL DESCRIPTION

The solder/bonding machine and the assembly fixture (Figure C-1) are separate pieces of equipment.

C.1.1 ASSEMBLY FIXTURE

The assembly fixture is a 296-square-inch platform containing alignment and holddown devices to permit placing and securing solar cells for subsequent soldering or bonding operations. It is fabricated of aluminum with a silicone rubber working surface. The silicone rubber affords a non-abrasive high-friction surface on which to place and align cells. In addition, the rubber has sufficient resiliancy to accommodate the variations in material thickness while soldering or bonding over the 15 to 18 inch joint length. The alignment guides provide assistance in placing the cells on the fixture to assure their parallel and perpendicular alignment. A special "T" square was fabricated for use with the assembly fixture. This instrument is used for both alignment and cell tab folding purposes. It has a stainless steel blade 15-1/2 inches long x 2 inches wide x 0.062 inch thick, the edges of which have a 45 degree taper to facilitate creasing and folding operations.

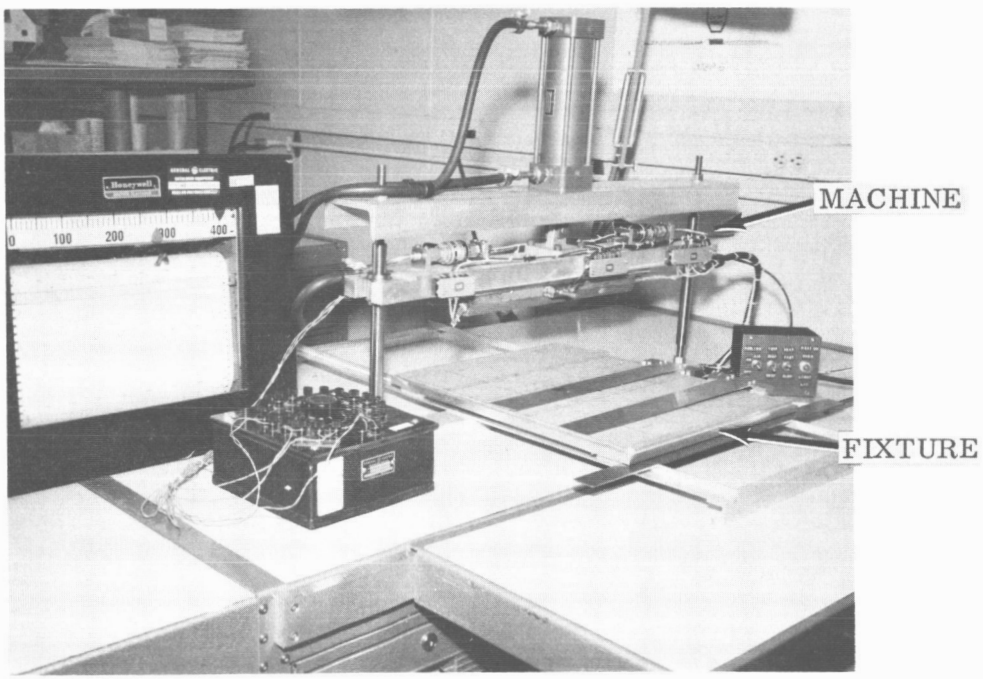


Figure C-1. Thin-Film Solar Cell Soldering/Bonding Machine and Assembly Fixture

For the soldered modules, once two rows of cells are aligned and fastened to the fixture, the fixture is placed on guides on the soldering/bonding machine and those operations performed. For conductive epoxy bonded modules, all the cells in the module are aligned on the fixture; then the epoxy is applied and the module and fixture are placed in an oven.

C.1.2 SOLDERING/BONDING MACHINE

The soldering/bonding machine is essentially a temperature-controlled bar mounted on a pneumatically actuated head. The assembly fixture, on which the work is to be soldered or bonded is placed on guides and moved into position under the head. The hot bar is then lowered onto the work piece and the particular operation, soldering, or bonding carried out. All temperature, time, and pressure settings are preset.

The machine is relatively simple to operate. A switching box allows easy selection of two preset solder/bond bar temperatures, air or water cooling of the solder/bonding bar, and a fast or slow heating rate. A foot pedal actuates the raising and lowering of the bar. The decent speed and contact pressure between the solder/bond bar and the work piece are preset by means of adjustable pressure valves and a regulator, respectively. Some of the machines features are:

a. The copper solder/bonding bar is heated by two 600-watt, rod-type heaters to provide quick, evenly distributed heat.

   Heat up rate - 100^{o}F/minute
   Heat distribution across - $\pm 5^{o}$F

b. Thermocouples attached at three locations on the bar and to a temperature recorder allow constant monitoring of the bar temperature.

c. An indicator light mounted on the switching box tells the operator when the selected temperature is reached.

d. Two adjustable thermostats are attached to the bar. They are used in conjunction with the switching box to provide selection of any two preset temperatures ranging from ambient to 600^{o}F.

e. The air cyclinder is of sufficient size to permit a 5 1/2 inch travel distance. This provides the operator with good visability for work placement under the bar.

f. The bar travels on ball bushings and precision, case-hardened shafts for minimum friction and maximum wear resistance.

g. Speed control valves permit variable bar decent speeds.

h. A foot-activated air control valve is used to raise or lower the bar. This frees the operators hands for other activities.

i. Solenoid valves in connection with a dc power supply and on-off-on switch provide capability for rapid cooling of the bar by either air or chilled water.

j. A pressure regulator in the air supply line provides the capability for presetting desired contact pressures.

k. The use of a separate mounting base makes the machine portable and easily installed.

l. Guide rails in the base provides positive means of positioning the assembly fixture in parallel with the bar.

Detailed operating instructions are provided in Appendix D.

C.2 INSTALLATION

The solder machine is portable and can be used on top any conventional work bench with surface dimensions of at least 36 x 42 inches.

C.2.1 ELECTRICAL REQUIREMENTS

110 volt ac for heaters and temperature recorder 28 volt dc for operation of the solenoid valves

C.2.2 PNEUMATIC SYSTEM REQUIREMENTS

23 psi air

C.2.3 COOLING SYSTEM

Copper tubing (1/4-inch OD) protrudes from each of the solenoid valves for hose connections to either air or water supply.

C.3 OPERATION

C.3.1 HEAT ADJUSTMENT

a. The switch marked "HEAT" on the control box is used to activate the heating elements and control the rate of heating. In the center position, the heat is turned off. Rapid heating is achieved by putting the heaters in parallel. To minimize the degree of drift beyond the operating temperature the heaters are put in series.

C.3.2 COOLING

There are three modes of cooling designed into the machine.

a. Cooling in ambient air - slow

b. Forced air - medium

c. Water - rapid

For most applications, forced air cooling will suffice and was the one used in solar cell joining. To cool using air or water, simply turn off the heat by placing the "HEAT" switch in the center position and place the "COOL" switch in the "on" position.

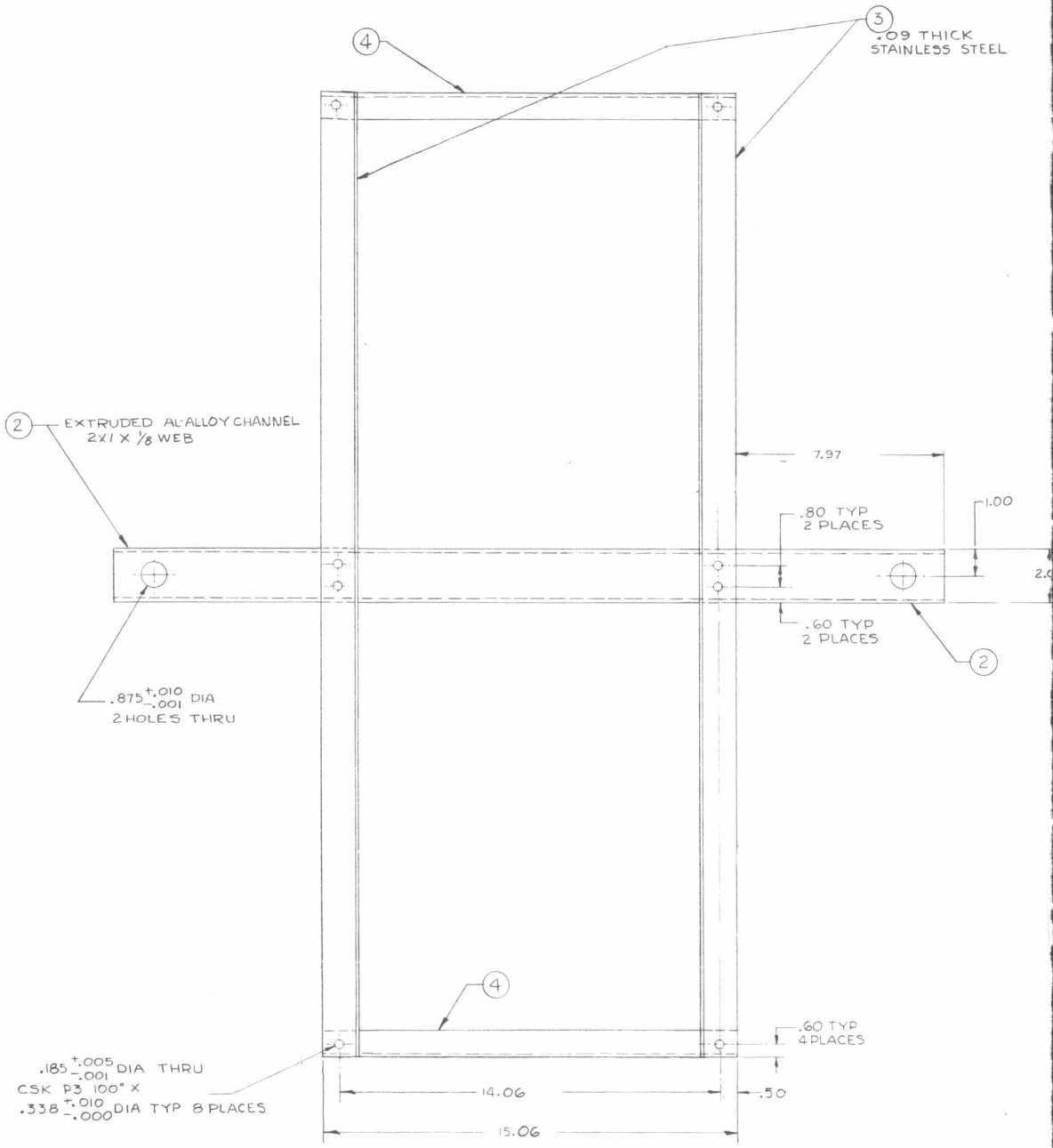
For ambient air cooling the "HEAT" switch is turned off.

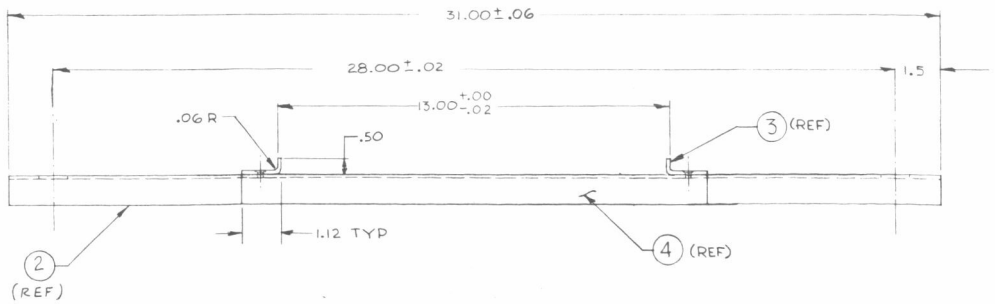
C.3.3 TRAVEL SPEED ADJUSTMENT

The speed at which the bar moves up and down is regulated by adjusting the screws on each of the two air control valves located on the foot pedal assembly (Figure C-8).

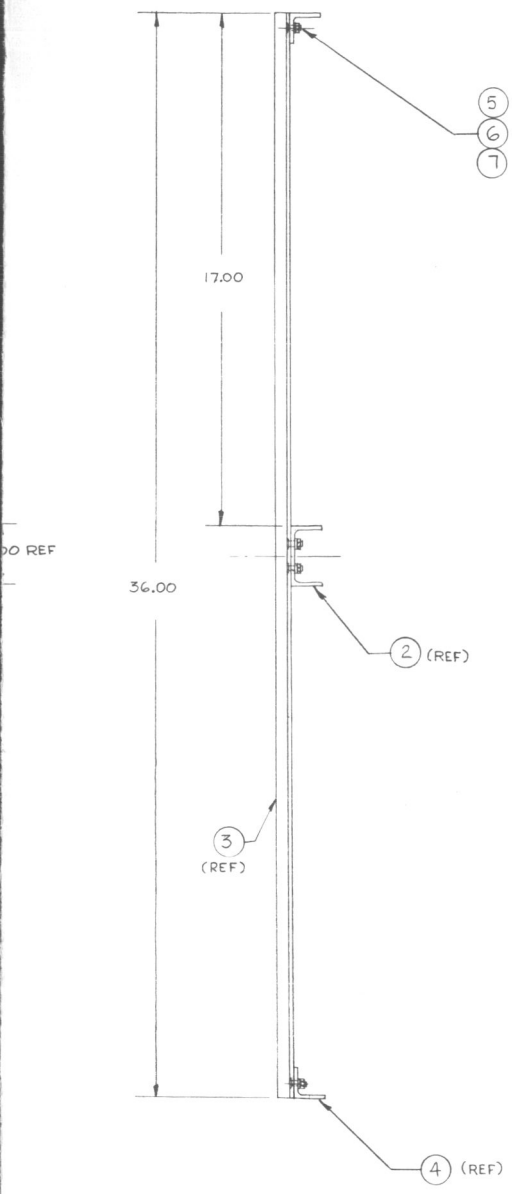
C.3.4 PRESSURE CONTROL

The contact pressure of the solder bar against the work peice is controlled by adjusting the incoming line pressure.



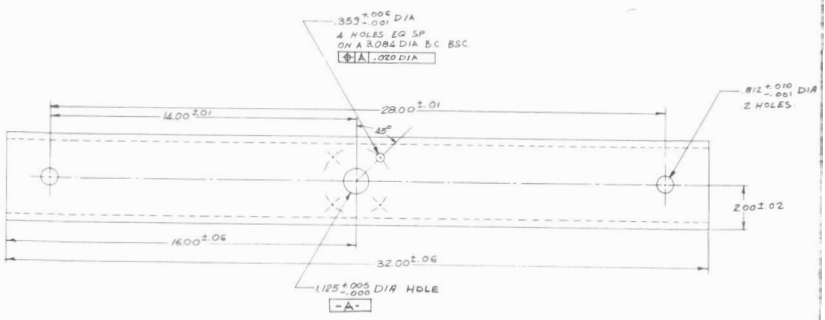


FOLDOUT FRAME 1

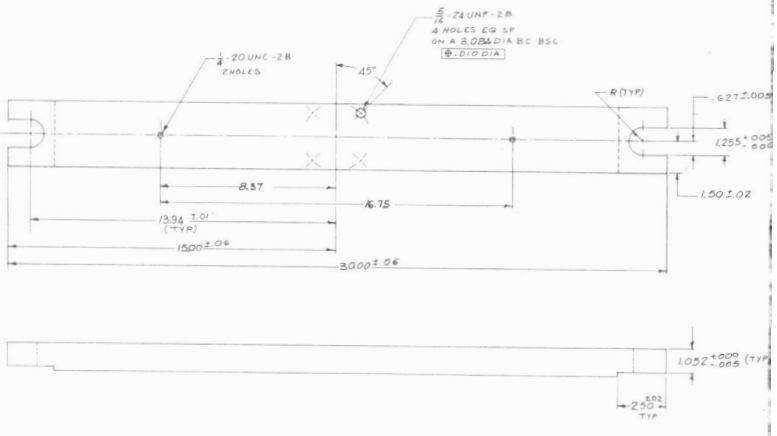


NOTES:
1. INTERPRETATION OF DRAWING TERMS AND TOLERANCES PER 118A1664.

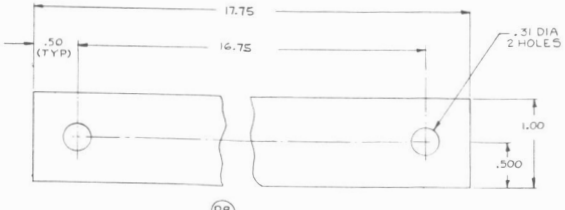
Figure C-4. Base Assembly



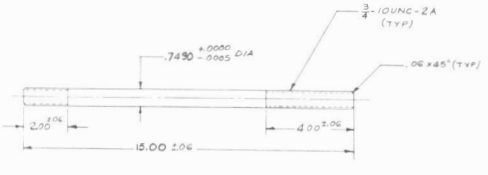
(P2) MAT'L: 4 x 1.58 x .180 STRUCTURAL CHANNEL
AL ALLOY
SCALE 1/2



(P3) MAT'L: 1.25 X 3.0 RECTANGULAR BAR
AL ALLOY
SCALE 1/2

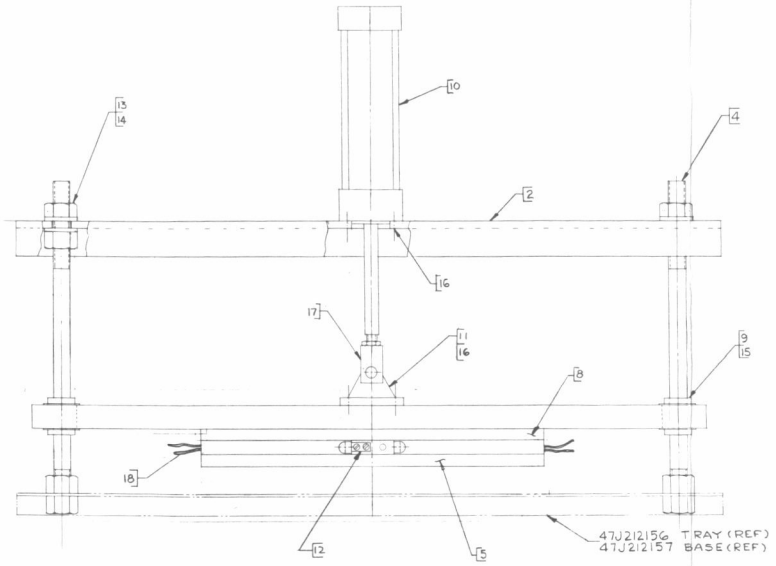


(P8) MAT'L :- ASBESTOS SHEET x.50 THK
SCALE 2:1 PC. NO. 9338PS



(P4) POST
MAT'L: CRES

FOLDOUT FRAME 1



NOTE:

1. INTERPRETATION OF DRAWING TERMS AND TOLERANCES PER 11B41664.

VENDOR NOTE:

A. WATLOW 12001 LACKLAND RD. ST LOUIS, MISSOURI 63141.
B. HANNIFIN PNEUMATIC DEVISION. 500 S. WOLF ROAD. DES PLAINS, ILLINOIS 60016.
C. THOMSON INDUSTRIES, INC. MANHASSET NEW YORK. % MOFFATT BEARINGS CO. 1640 FAIRMOUNT AVE. PHILADELPHIA, PA, 19130
D. MCMASTER-CARR SUPPLY CO. PO BOX 4355 CHICAGO, ILLINOIS 60680. ORDER INSULATOR 9338P5.

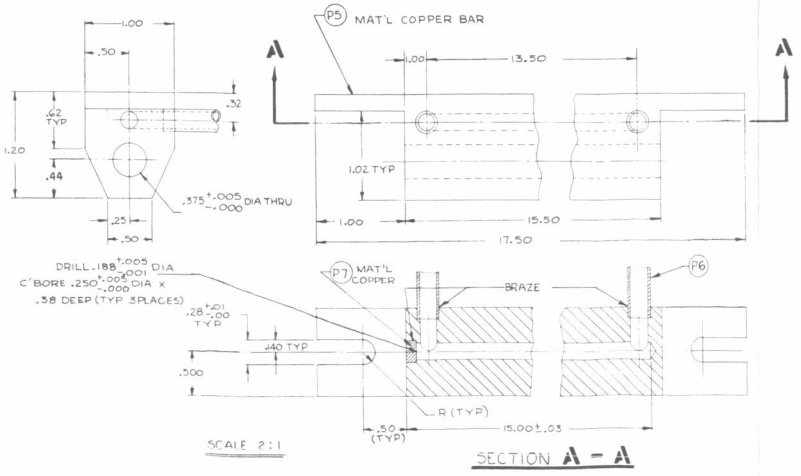
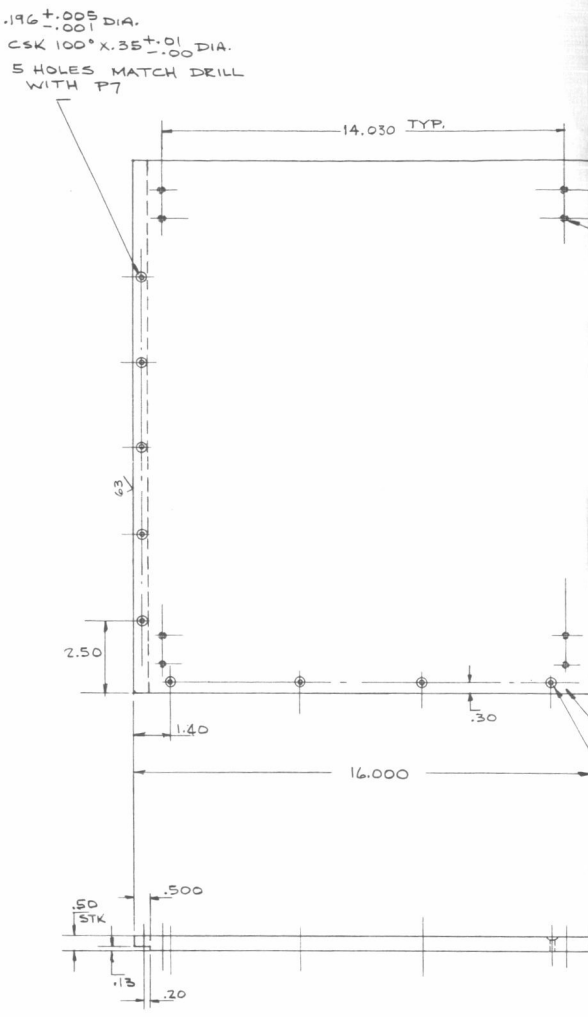
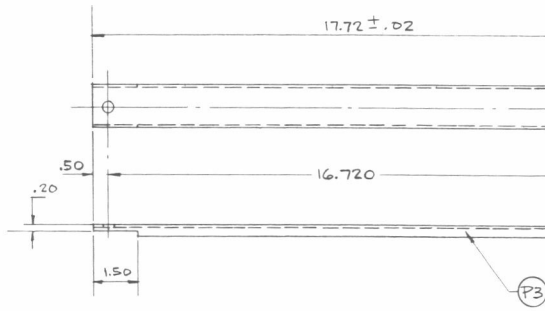
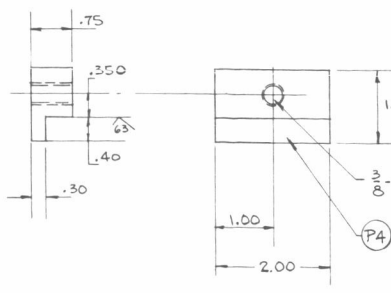


Figure C-3. Solder/Bonding Machine Assembly

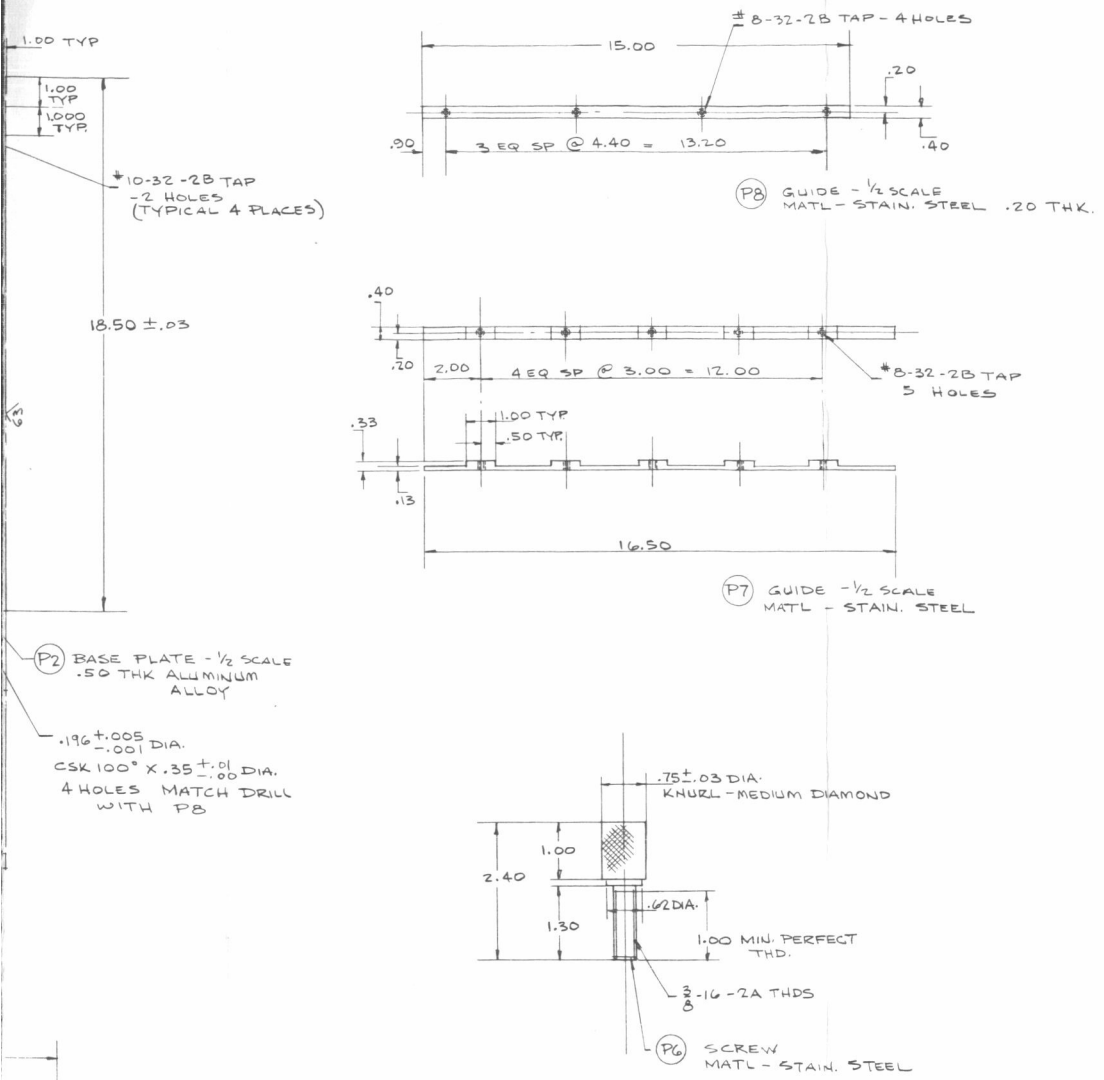
FOLDOUT FRAME 2

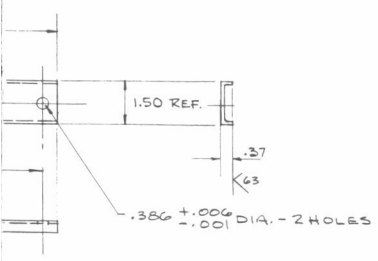




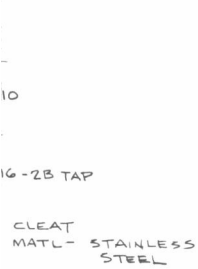


FOLDOUT FRAME 1





Beam - 1/2 SCALE
MATL - 1 1/2 x 1/2 x 1/8 THK
ALUMINUM EXTRUDED
CHANNEL



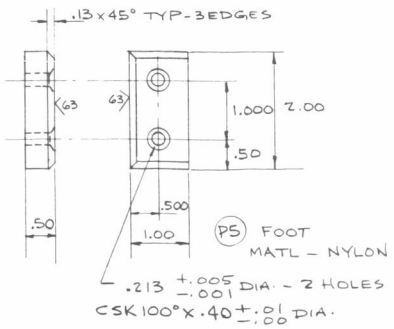
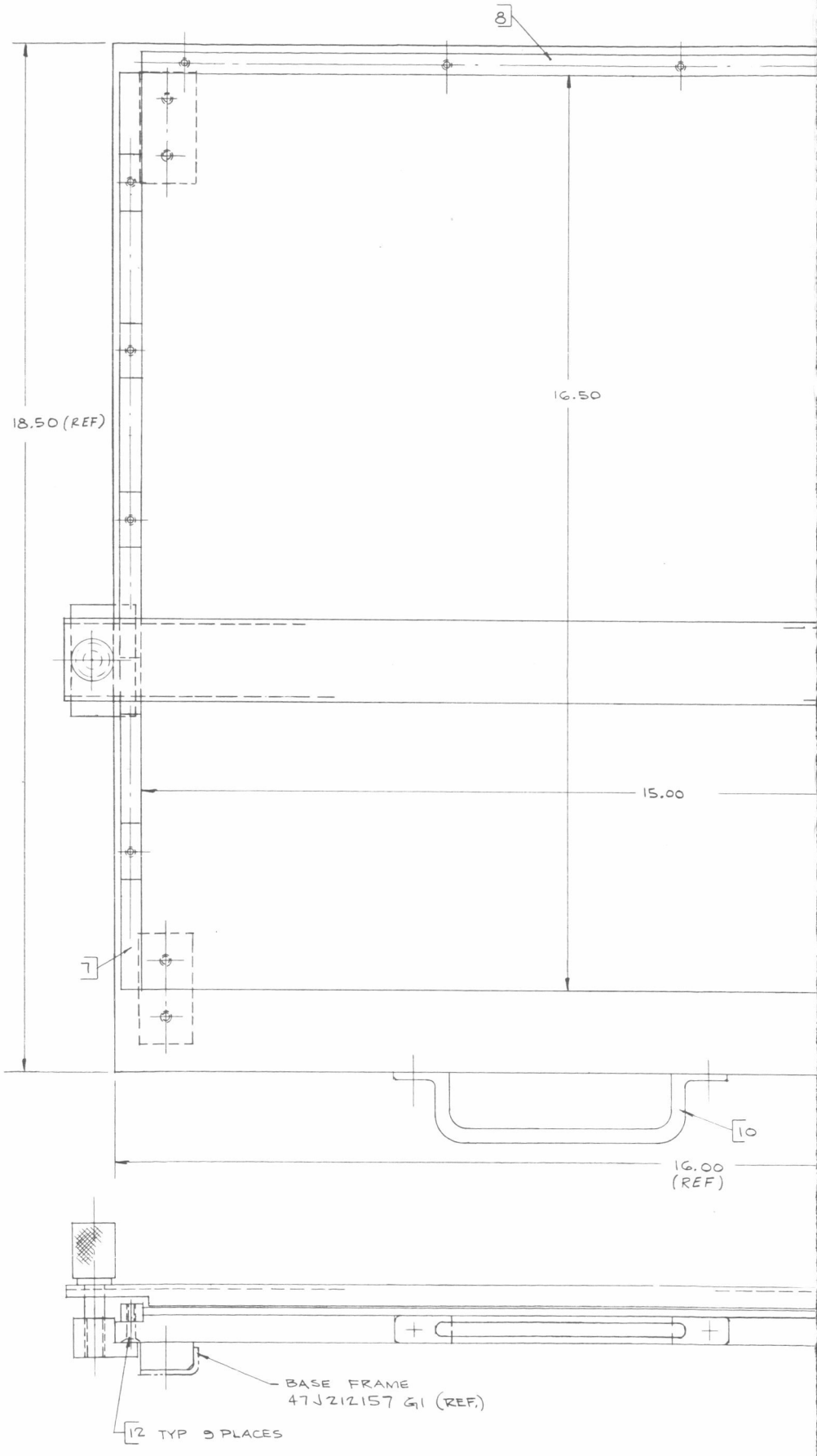
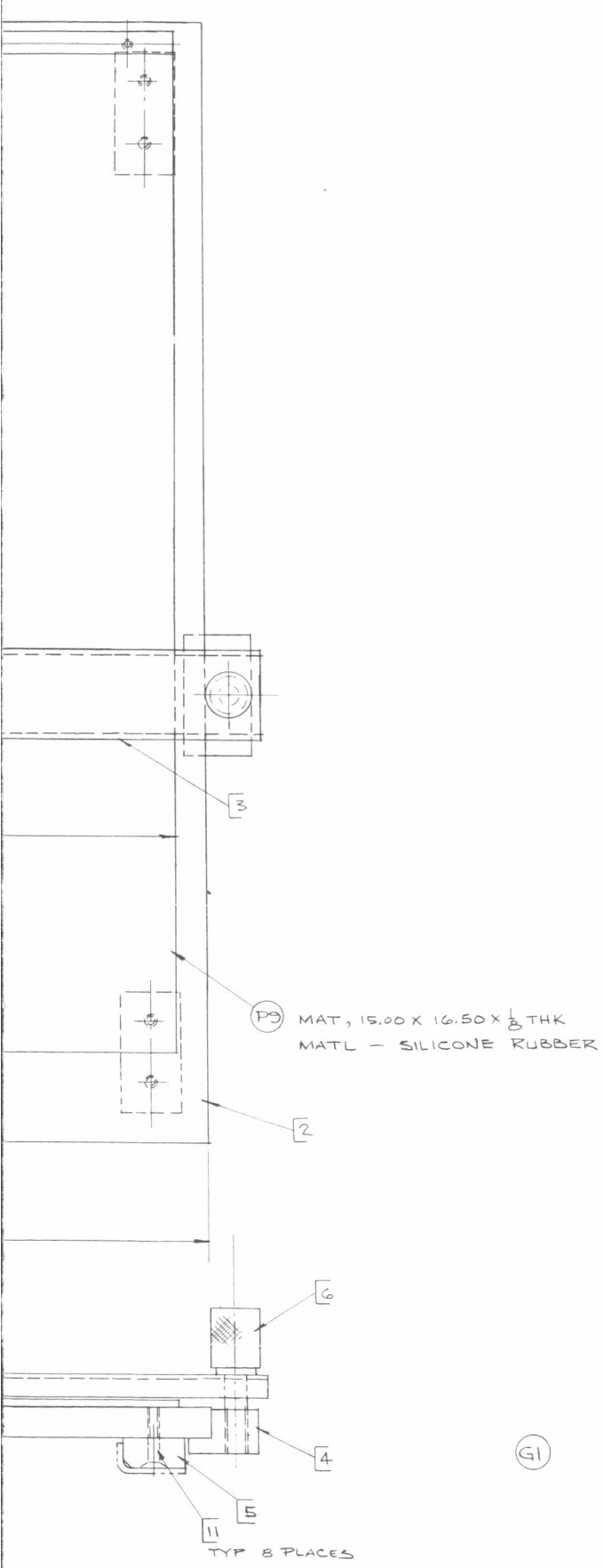


Figure C-2. Module Assembly Fixture
(Sheet 2 of 2)

FOLDOUT FRAME 2



FOLDOUT FRAME 1



NOTES :–

1. DRAWING TERMS & TOLERANCES PER 118A1664.

Figure C-2. Module Assembly Fixture (Sheet 1 of 2)

FOLDOUT FRAME 2

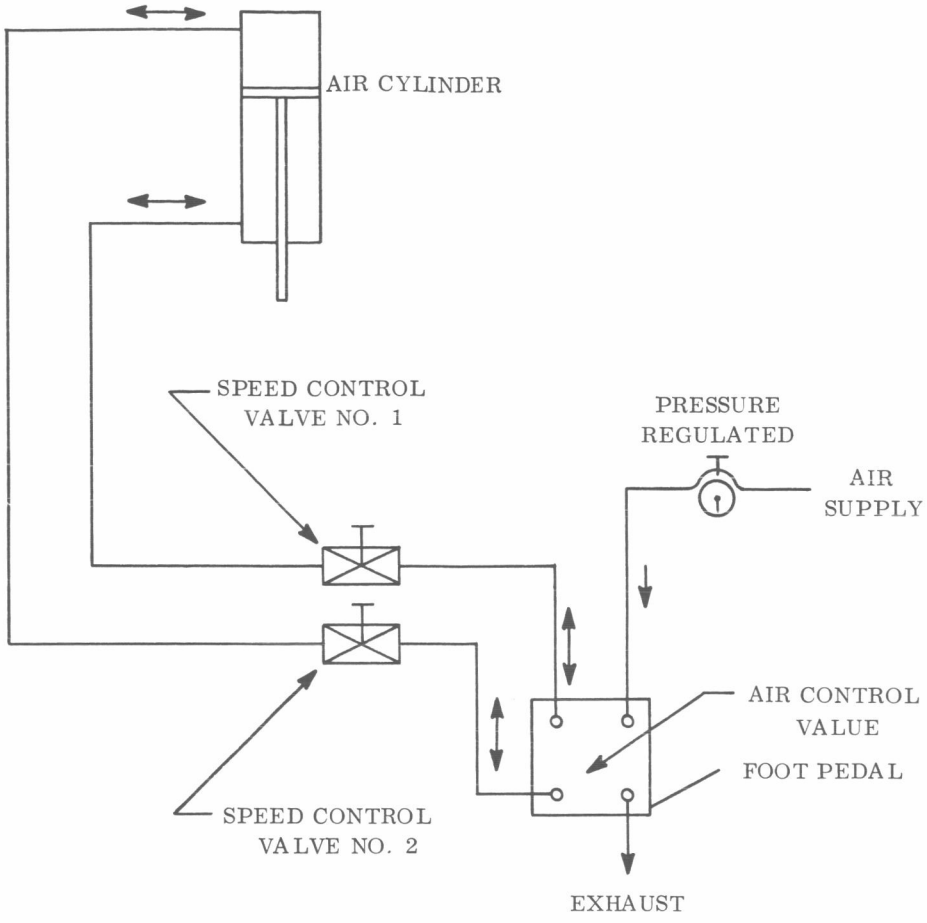


Figure C-7. Pneumatic System

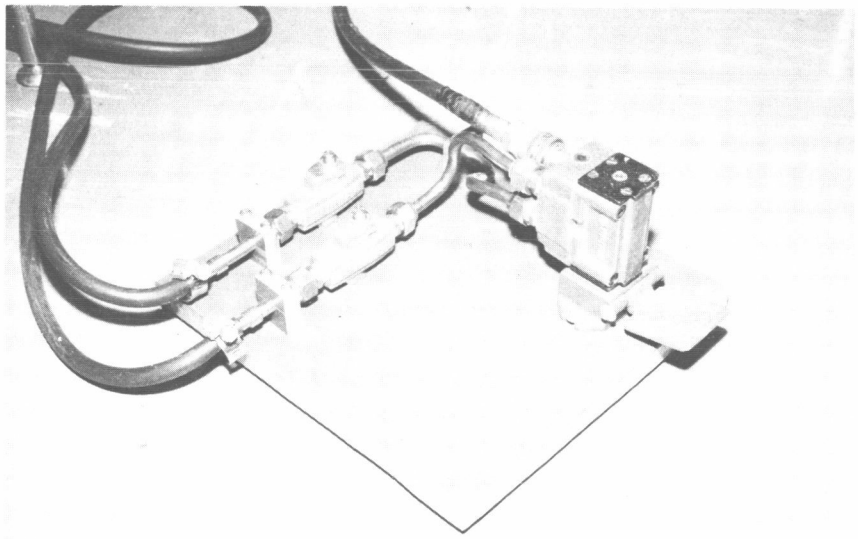


Figure C-8. Foot Pedal Assembly

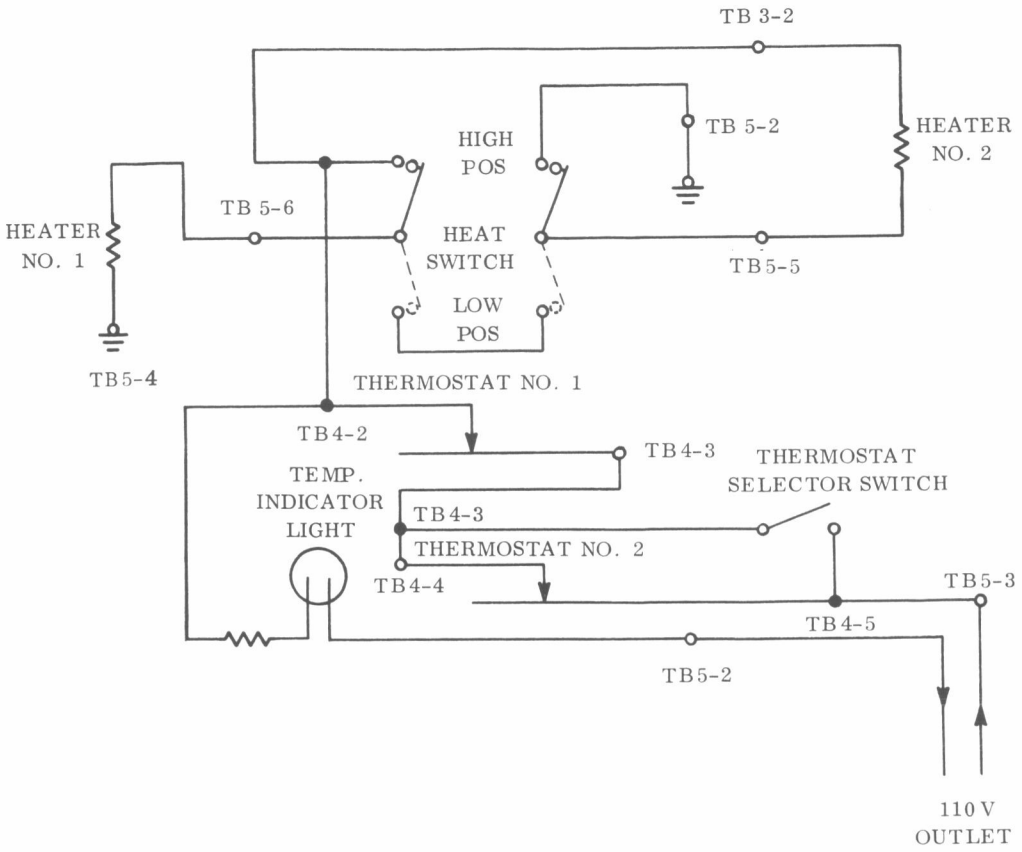


Figure C-5. Heater Circuit

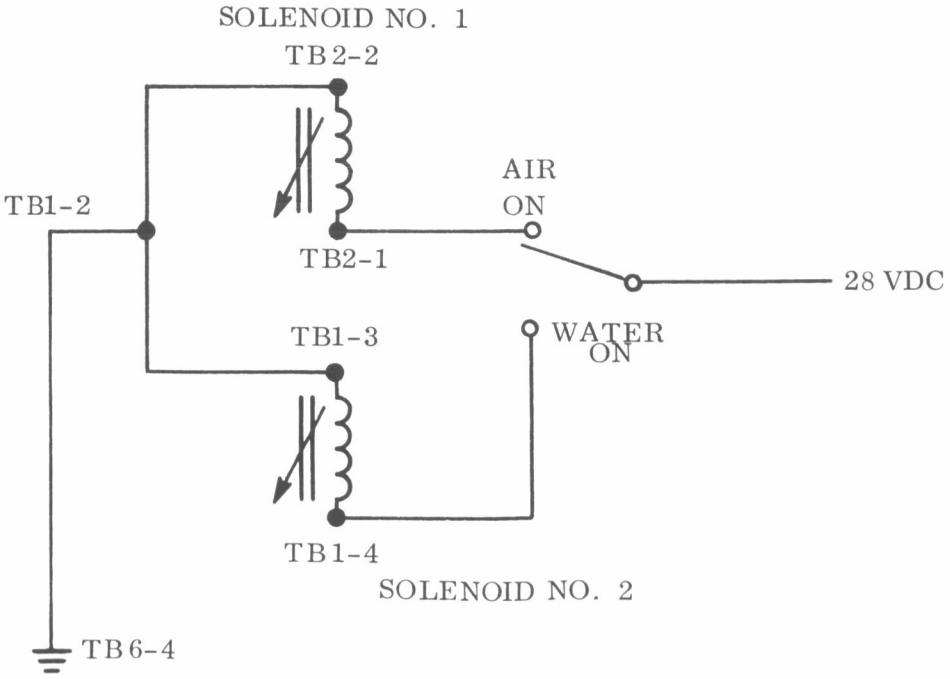


Figure C-6. Heater Cooling Circuit

APPENDIX D

FABRICATION PROCEDURES FOR CdS THIN FILM SOLAR CELL MODULE FABRICATION

D.1 INTRODUCTION

Many of the operations used for cell joining are exacting and may critically affect the quality of the end product. Therefore, this appendix contains the detailed procedures used to achieve reliable solder and/or adhesive bonds. These procedures were used to fabricate CdS thin film solar cell modules 5 cells wide (connected in parallel) by 5 cells long (connected in series) by using either a solder/adhesive bond combination or a conductive joining method. The modules were built to the configuration control drawing 47D214515, Figure D-1. A completed module is shown in Figure D-2.

D.2 CELL PREPARATION

To meet the dimensional requirements of the module configuration control drawing (Figure D-1), it was necessary to trim the individual cells shown in Figure D-3 to a standard size prior to the joining operations. This was accomplished using a template and an X-acto knife as described herein.

D.2.1 EQUIPMENT AND MATERIALS

a. Trim template - 2.85" x 3.30" cut from 3/16" thick aluminum sheet.

b. Covered on one side with "Teflon" tape.

c. Trim block - 12" x 12"x 1" block of wood or plastic.

d. X-acto knife or equivalent.

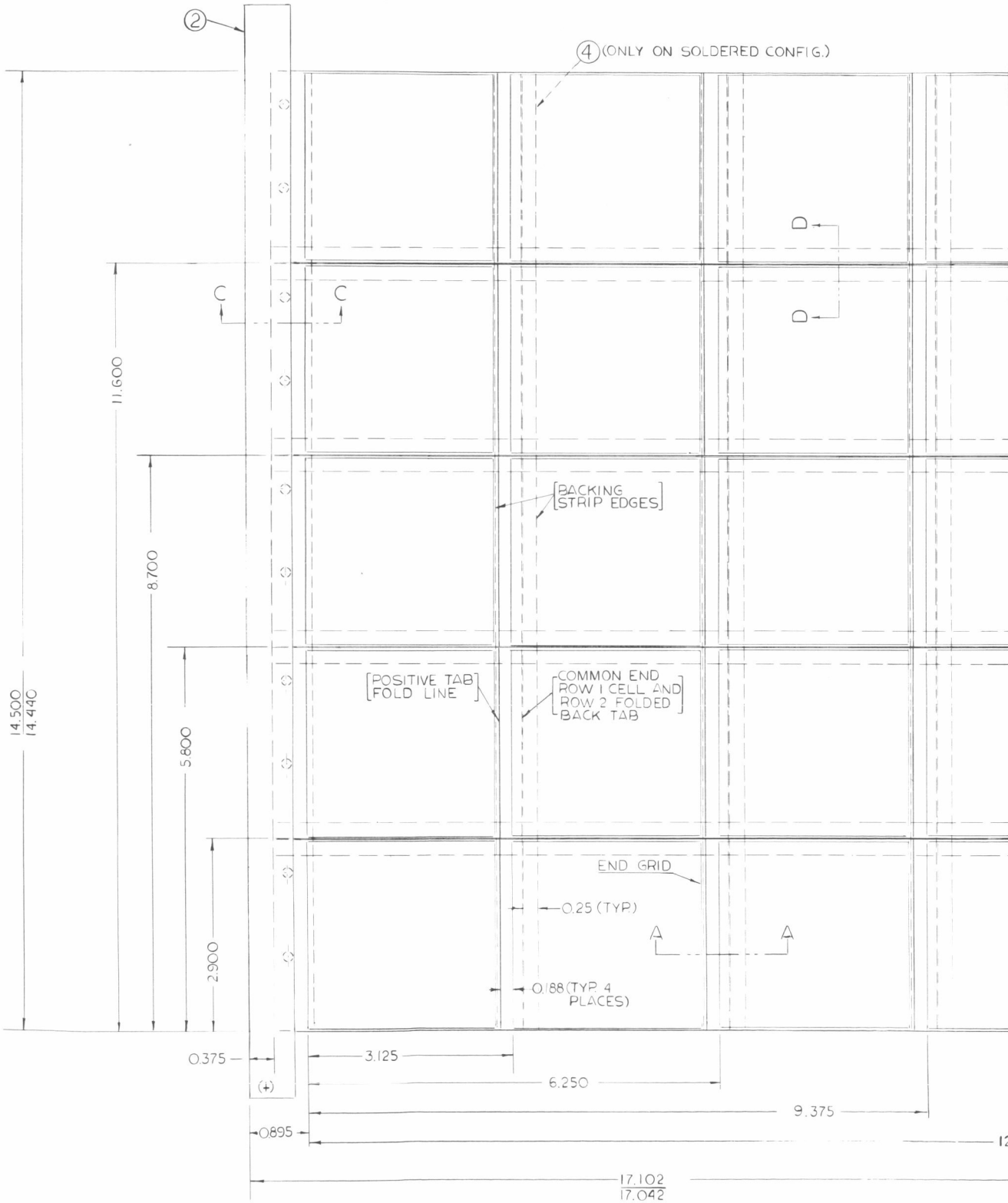
e. Clevite CdS solar cells (Ref. Figure-3) - 25 per module.

D.2.2 PROCEDURE

a. Lay a cell on the trimming block with the active (dark) surface up.

b. Place the trim template ("Teflon" side down) on the cell and trim as shown in Figure D-4 and as follows:

   1. Align the left 3.30-inch edge of the trim template along the inside edge of the grid pattern running perpendicular to the width (narrowest dimension) and on the left side of the cell as it faces you.



FOLDOUT FRAME 1

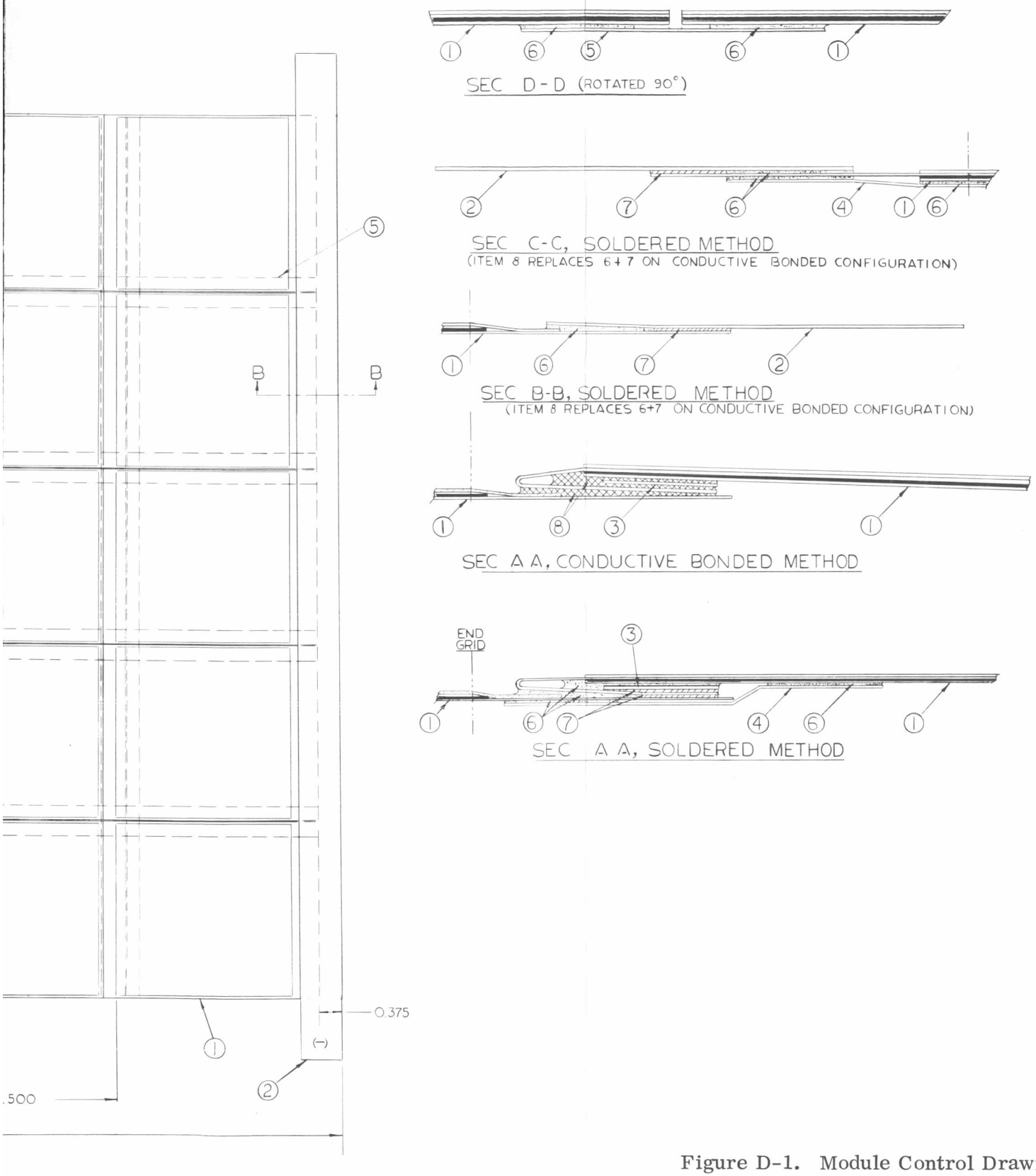


Figure D-1. Module Control Drawing

FOLDOUT FRAME 2

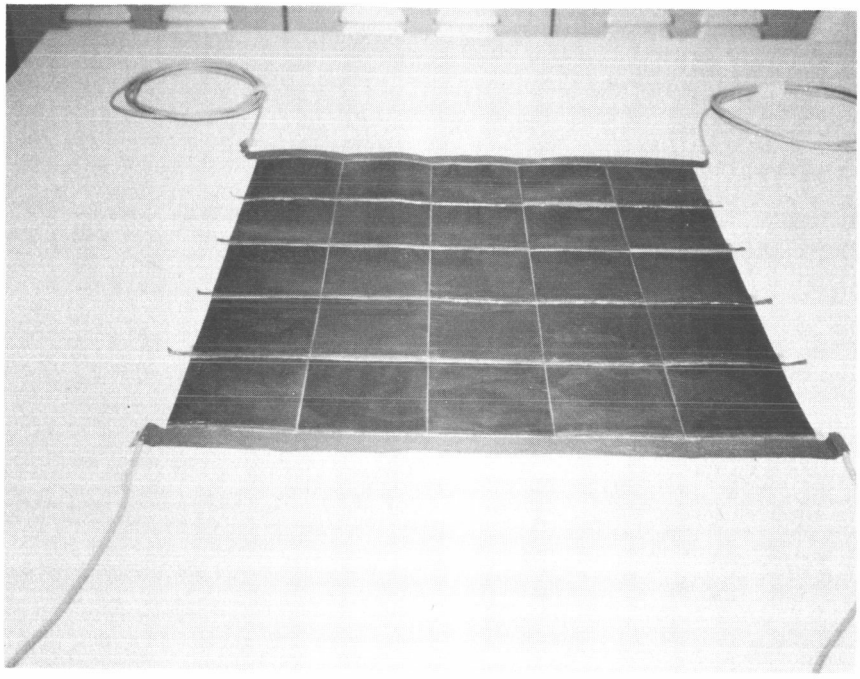


Figure D-2. Completed (5-Cell x 5-Cell) CdS Thin-Film Solar Cell Module

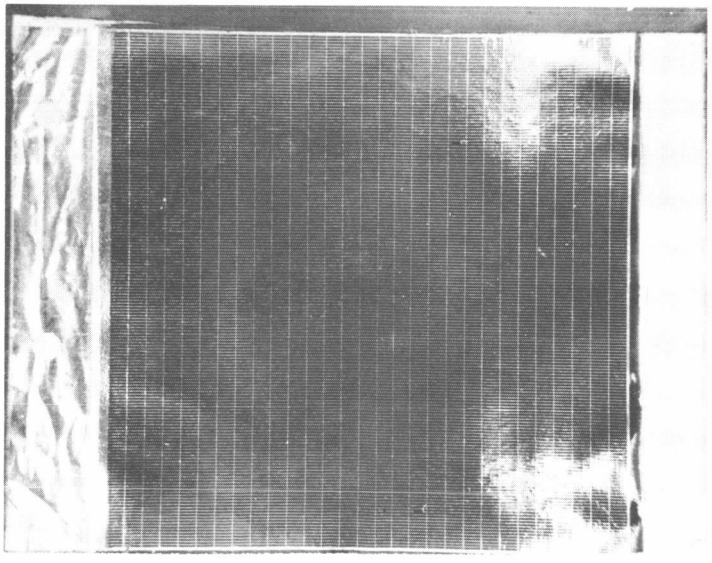


Figure D-3. Clevite CdS Thin-Film Solar Cell

2. Trim off the portion of the cell which extends beyond the opposite edge of the template using an X-acto knife. (Right side of cell).

   NOTES: A keen cutting edge is required for trimming operations. Change blades as required.

3. Repeat steps 1 and 2 aligning along the right side to trim the opposite edge of the cell.

4. Align the 2.85-inch end of the template along the inside edge of the grid adjacent to the copper foil (positive) tab of the cell.

5. Trim off the portion of the plastic (negative) tab that extends beyond the opposite end of the template.

D.3 SOLDERED MODULE

Soldered modules require the addition of an adhesive support to strengthen the solder joint. The steps for the construction of a reinforced joint is shown in Figure D-5.

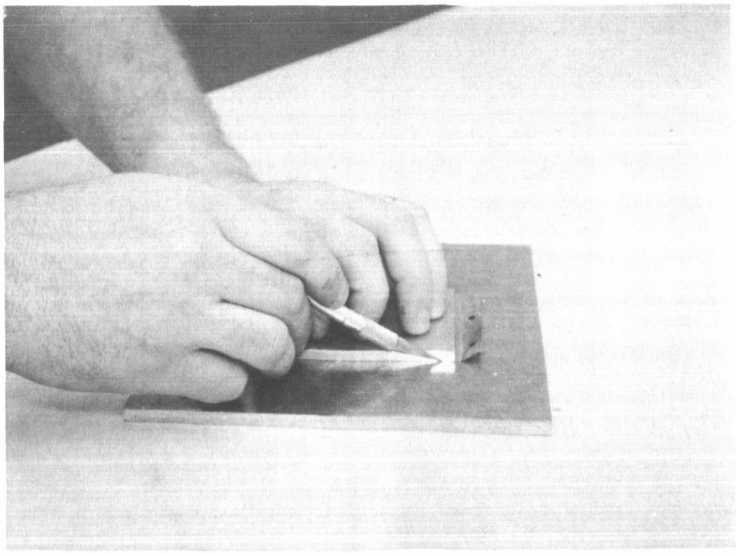
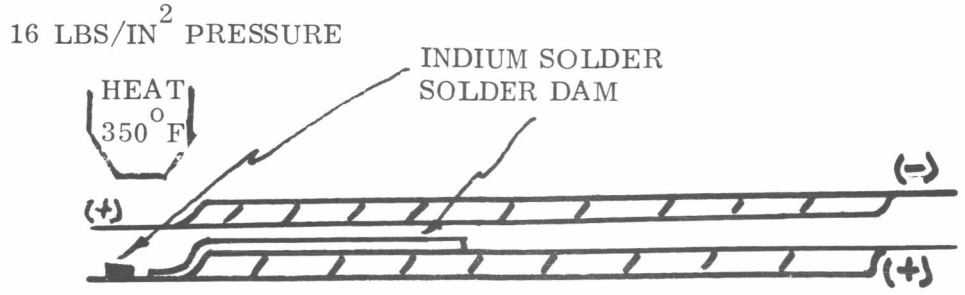
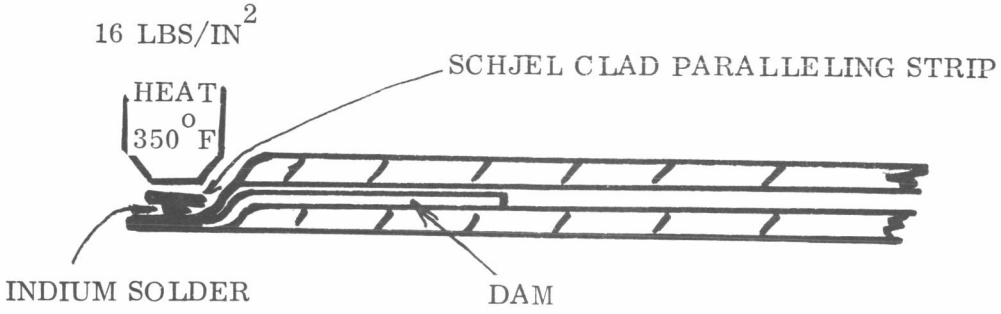


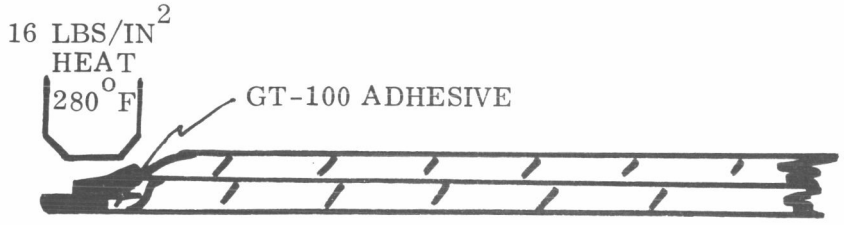
Figure D-4. Trimming Solar Cells



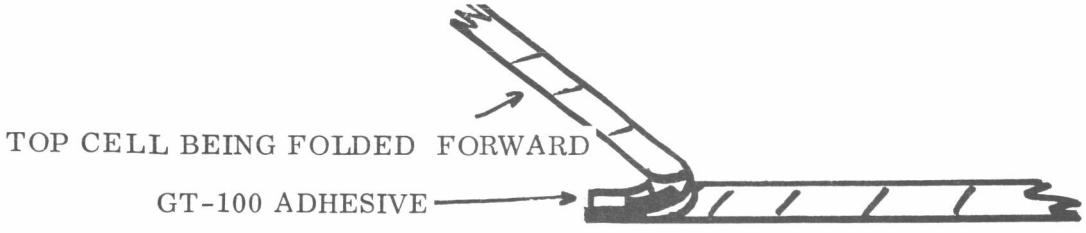
a. Placement of solder preform and cells



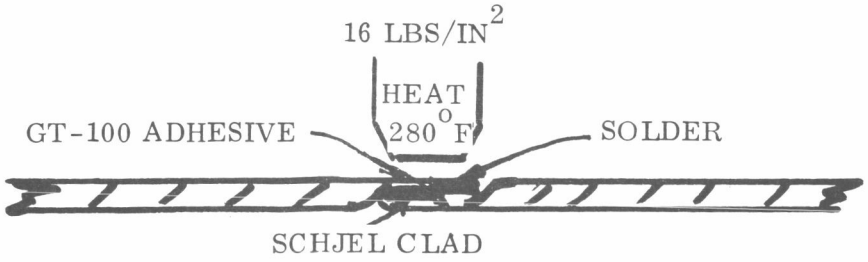
b. Soldering Schjel Clad to the copper (+) tab of the cells.



c. Dam removal and bonding with Schjeldahl GT-100 Adhesive



d. Cell folding and GT-100 placement



e. Fold completed and cells turned over for final GT-100 bond.

Figure D-5. Steps for Making a Reinforced Solder Joint

D.3.1 EQUIPMENT, MATERIALS AND PREPARATION

a. Clevite CdS Thin Film Solar Cells - 25 cells trimmed as described in Section D.2 of this appendix.

b. Assembly Fixture 47J212156 and "T" square.

c. Solder/Bond Machine 47J212158.

d. Hand soldering iron controlled at 500°F.

e. "Kapton" strip (0.003 x 2 x 16 x 16 inches) - used as a dam to control the flow of solder.

f. "Kapton" strip (0.001 inch x 0.75 ± 0.25 inch x 16 inches) - used between the heater bar and the cell during soldering and bonding operations to prevent solder and adhesive contamination of the heater bar. This also minimizes sticking of the cells to the bar during these operations.

g. Pressure sensitive masking tape and dispenser - any source.

h. Alpha 709 solder flux

i. Artist Brushes

j. Alpha No. 235 (151°C) indium Bismuth Solder performs as specified below:

	Qty	Dimension
a.	4	0.005" x 1/16" x 11-1/2"
b.	2	0.005" x 1/8" x 11-1/2"

k. Schjel Clad L-5550 Paralleling Strips as specified below:

	Qty	Dimension
a.	4	0.003" x 3/16" x 11-1/2"
		Tack solder a preform (item 3.1.10a) to each strip.
b.	2	0.003" x 1/2" x 11-1/2"

l. Schjeldahl GT-100 adhesive strips as specified below:

	Qty	Dimension
a.	6	0.0025" x 3/16" x 16"
b.	4	0.0025" x 3/8" x 16"

m. Fluorocarbon solvent such as "Genesolv" or "Freon."

n. Cotton swabs.

D.3.2 PROCEDURES

D.3.2.1 Cell Alignment on Assembly Fixture

Place five cells active (dark) surface up on the assembly fixture 47J2156 shown in Figure D-6 and according to the following procedure:

a. Use the edge of the grid pattern nearest the plastic(-) tab of the cell for alignment purposes.

b. Align the "T" square along line on the assembly fixture (see Figure D-6).

c. Starting at the upper left hand corner of the assembly fixture, slide the plastic (-) tab of the first cell under the "T" square.

NOTE: The "T" square may be tipped slightly to facilitate cell placement and alignment.

d. Center the cell between the vertical lines A&B on the fixture and align the edge of the grid pattern along the edge of the "T" square.

e. Secure the cell to the fixture with pressure sensitive tape.

NOTE: Secure at two points to prevent the cell from skewing during subsequent operations (Figure D-7a)

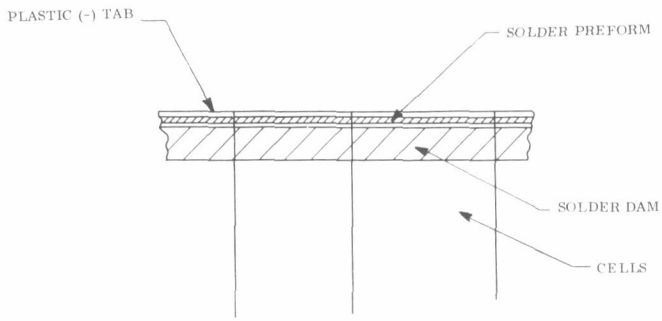
f. Position the second cell in a similar manner and secure to the previously placed cell (Figure D-7a).

g. Continue this alignment and securing operation until the row is completed and secured to the fixture (Figure D-7a).

h. Place the "Kapton" dam (Section D.3.1, Item e) on top of the cells and aligned along line 2 on the assembly fixture (Figure D-7). Secure at each end with pressure sensitive tape. Anchor the top edge of the dam at several locations to the cell surfaces also.

i. Apply flux to the exposed portion of the plastic (negative) tab. Use an artists brush for this operation.

j. Place a 1/16-inch-wide solder ribbon preform on top of the fluxed tabs between the edge of the tabs and the dam. See sketch below.



SKETCH SHOWING SOLDER PREFORM PLACEMENT

k. Spot tack the ribbon to the tabs using a 500°F hand soldering iron. (See Figure D7-b.) Add flux to top of solder preform with an artists brush.

D.3.2.2 Alignment of Second Row of Cells

Place a second row of five cells on top of the first row of cells as follows:

a. Starting in the upper left corner, place the first cell active (dark) surface down and with the copper (positive) tab over the plastic tab of the cell in the fixture.

b. Align the cell directly over the bottom cell and with the copper tab along line 3 on the fixture (Figures D-6 and D-7c).

NOTE: The plastic tabs extend 1/16" beyond the edge of the copper tab.

c. Use the "T" square to facilitate alignment.

d. Continue the cell placement and alignment until the second row is completed and secured to the fixture.

e. Place a "Kapton" barrier strip (Section D.3.1, Item f) over the joint to be soldered.

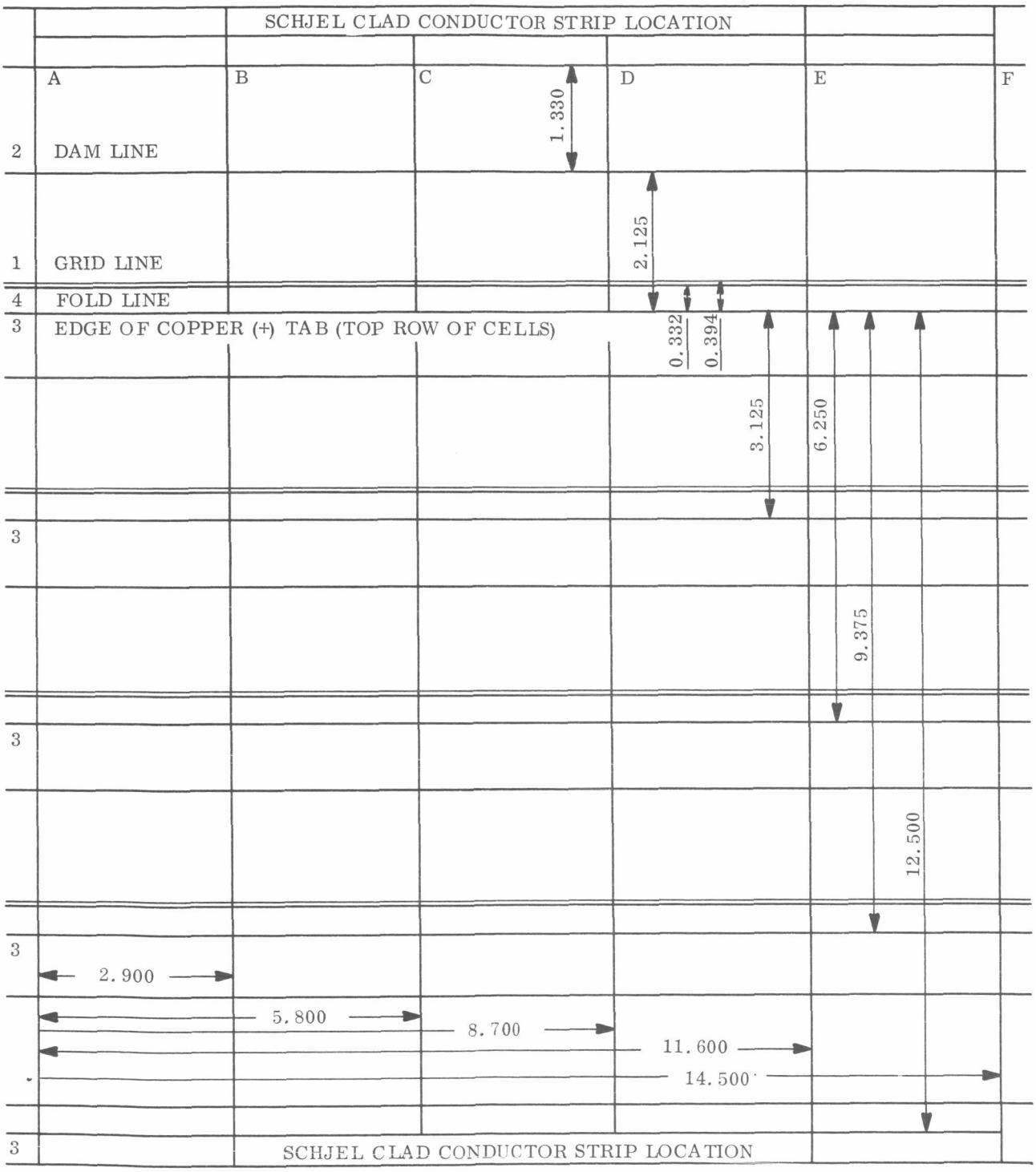
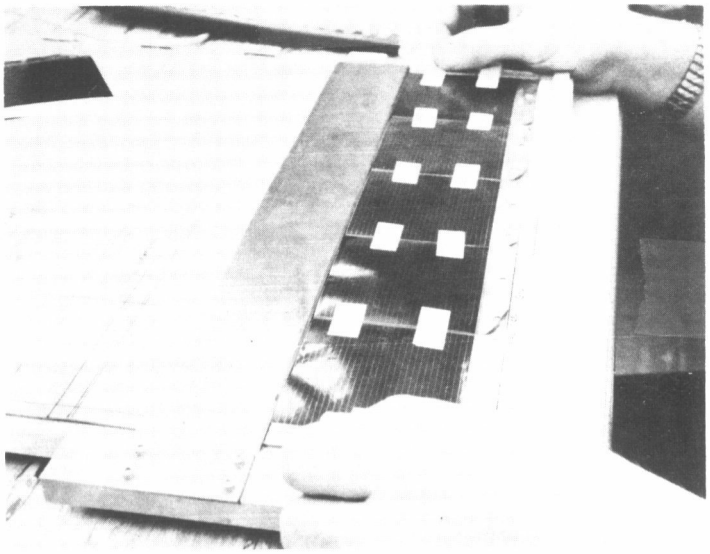
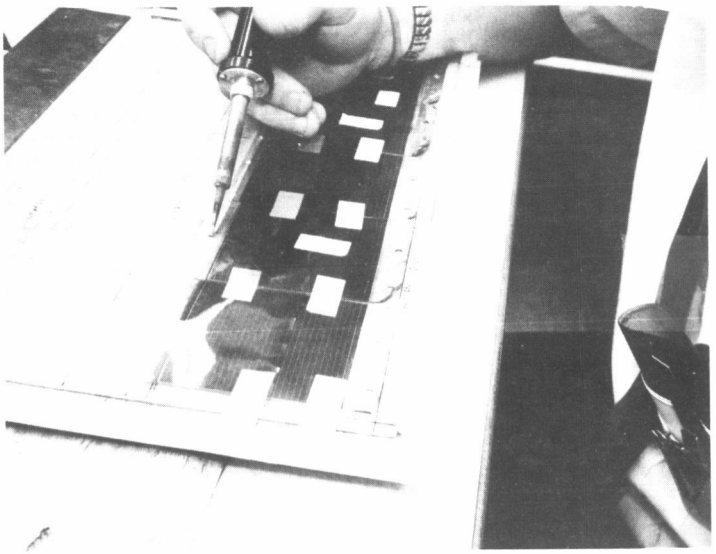


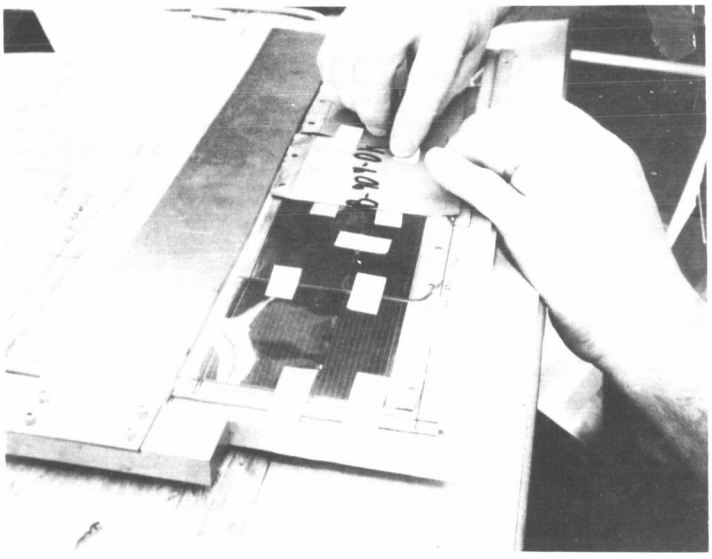
Figure D-6. Pattern Layout on Assembly Fixture for Cell Aligning and Folding Operations



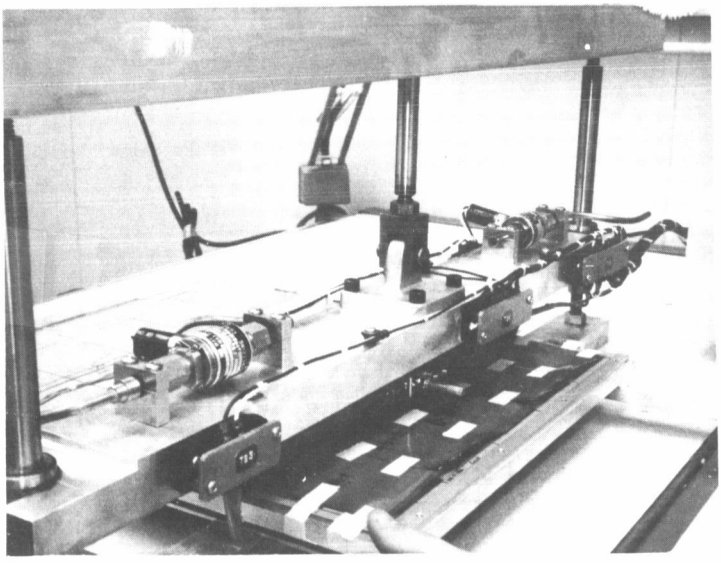
a. Cell Alignment (first row)



b. Tack Bonding Solder Preform



c. Cell Alignment (second row)



d. Soldering Using Solder Machine

Figure D-7. Module Fabrication Procedures

D.3.2.3 Soldering Procedure

a. Place the assembly fixture on the guide tracks of the soldering/bonding machine 47J212158.

g. Slide the assembly into position under the preheated (350 ± 5F) solder bar. (See Appendix C for operation of solder/bond machine.)

c. Lower the solder bar onto the cell tabs and hold at 16 lb/in^2 and $350^{o}F$ for two seconds. (Figure D-7d).

NOTE: For pressure regulation see Paragraph 4.4, Appendix C.

d. Start forced air cooling of bar.

e. Cool to below $300^{o}F$.

f. Raise bar.

g. Remove "Kapton" barrier strip.

h. Remove squeezed out solder - use the $500^{o}F$ hand iron for this operation.

D.3.2.4 Application of Schjel Clad Paralleling Strip

a. Apply flux to copper (positive) tabs.

b. Place a piece of Schjel Clad ribbon, which has a 1/16 inch wide solder preform tack soldered to it (Section D.3.1, Items k, a), on top of the fluxed tabs. (Figure D-5b)

NOTE:
- Solder preform on the Schjel Clad is fluxed just prior to this operation.
- The Schjel Clad strip is positioned along the outer edge of the copper tabs.

c. Place a "Kapton" barrier strip over the Schjel Clad.

d. Solder as described in Section D.3.2.3, steps a and b.

e. Hold at 16 lb/in^2 and 350^{o} for 6 seconds, then raise the bar.

f. Lift the top row of cells and remove the "Kapton" solder dam from between the cells.

g. Clean off residual flux using a cotton swab saturated with fluorocarbon solvent.

h. Align the "T" square along the fold line 4 indicated on the fixture (Figure D-6).

i. Lift the top row of cells and press the copper tabs against the edge of the "T" square using a gloved finger to produce a creased fold line.

CAUTION: Crease, but do not fold. A bond with GT100 must be made prior to folding.

j. Remove the "T" square.

D.3.2.5 Application of Schjedahl GT-100 Adhesive

a. Place a 3/16 inch wide strip of GT-100 adhesive between the cells and against the solder joint. (Figure D-5c).

b. Spot tack into position using a 500^{o}F soldering iron.

c. Place a 3/8 inch wide strip of GT-100 adhesive on top of the Schjel Clad and spot tack into position. (Figure D-5d).

d. Fold the top row of cells forward and make a permanent fold along the crease line made in Section D.3.2.4h.

e. Place the assembly fixture in the solder-bond machine and position the joint to be bonded under the bar.

NOTE: Bar is preheated to 280^{o}F.

f. Lower the heated bar and hold for 12 to 14 seconds at 16 lbs/in.^{2}

g. Raise bar and remove the assembly fixture.

Add additional rows of cells using the above procedures until all the cells are joined.

D.3.2.6 Complete the Module as Follows:

a. Place a "Kapton" dam along the positive end of the module to within approximately 1/8 inch of the outer edge of the cells.

b. Secure with pressure sensitive tape.

c. Place a 1/16 inch ribbon solder preform over the exposed portion of the tabs.

d. Spot tack the solder preform.

e. Apply flux to the solder joint.

f. Place a fluxed 11/16 inch wide strip of Schjel Clad over the tabs with one edge aligned 3/16 inch away from the edge of the grid pattern at the positive end of the module.

g. Place a "Kapton" barrier strip on top of the Schjel Clad.

h. Solder as in previous operations.

i. Remove the dam and clean the joint with a fluorocarbon solvent.

j. Place a 3/16 inch wide strip of GT-100 adhesive under the unsoldered portion of the Schjel Clad between it and the cells.

k. Spot tack to secure.

l. Place "Kapton" barrier strip over joint.

m. Bond as in previous operations.

n. Repeat for the negative end of module.

NOTE: The Schjel Clad is aligned 1/8 inch from the edge of the grid pattern at this end of the module.

o. Remove all masking tape.

D.3.3 APPLICATION OF SEAM-BACKING STRIPS

D.3.3.1 Materials and Preparation

- 5/8 inch wide x 0.001 inch x 15 inch "Kapton" strips (4 each)
- 1/2 inch wide x 0.001 inch x 17-1/16 inch "Kapton" strips (4 each)
- GT-100 adhesive strips 3/16 inch wide x 17-1/16 inch long (4 each)
- GT-100 adhesive strips 3/16 inch wide x 15 inch long (4 each)

Tack bond a piece of 3/16 inch wide GT-100 adhesive along each edge the length of each "Kapton" strip.

D.3.3.2 Procedures for Back-up Strip Installation

a. Turn the module over (face down) and place on the assembly fixture.

b. Clean the solder/bond joints by wiping with fluorocarbon solvent.

c. Place a 15 inch long "Kapton" back-up strip over the solder/bond joint so that its center is in line with the center of the joint.

d. Secure in position by tack bonding the GT-100 using a 500^{O}F hand iron.

e. Repeat steps b through d for all horizontal seams.

f. Place assembly in the solder/bond fixture.

g. Bond as described in previous operation 3.2.5.

h. Remove the assembly from solder/bond machine.

i. Center a 17-1/16 inch long "Kapton" back-up strip over each of the vertical butt joints between the cells and spot tack as in d above.

j. Rotate the assembly fixture 90 degrees and place under the heated bar of the solder/bond machine.

k. Bond each strip as described in operation 3.2.5.

D.4 BONDED MODULE

The following procedures were used to join thin film "Clevite" cadmium sulfide solar cells into 25 cell (5 cell x 5 cell) modules by bonding with a conductive epoxy adhesive.

D.4.1 MATERIALS AND EQUIPMENT AND PREPARATION

D.4.1.1 Cadmium Sulfide Solar Cells - CC751863 - 25 each trimmed as described in Section D.2 of this appendix.

D.4.1.2 Cell Trim Template

D.4.1.3 X-acto knife and blades

D.4.1.4 Schjeldahl GT-100 adhesive

D.4.1.5 "Kapton" (100 x H667) film

- Prepare four (4) "Kapton" back-up strips (0.001 x 0.5 x 17.0 inches) per module by tack bonding a 3/16 inch wide strip of Schjeldahl GT-100 adhesive along each edge of the "Kapton" strips. Use a soldering iron at about 500°F for the tacking operation.

D.4.1.6 Soldering iron

D.4.1.7 Pressure sensitive tape and dispenser

D.4.1.8 Assembly fixture (Figure D-8)

D.4.1.9 "T" square

D.4.1.10 SMRD 745 adhesive, General Electric Co.,
Space Systems Operations
Box 8555, Phila., Pa., 19101

D.4.1.11 Schjel Clad - L5550

- Cut two (2) strips of Schjel Clad 11/16 inch wide x 17 inches long and four (4) strips 3/16 inch wide x 17 inches long.

D.4.1.12 Silver Flake - "ALCAN" MD755

D.4.1.13 Balance accurate to within $\pm$ 0.5 gram

D.4.1.14 Paper (unwaxed) cups or beakers

D.4.1.15 Wooden or plastic tongue depressors

D.4.1.16 Cotton swabs

D.4.1.17 Teflon pressure sensitive tape (1/2 inch wide)

D.4.1.18 Teflon tape (0.5 inch wide x 0.005 inch thick) nonsticky - 6 strips

D.4.1.19 0.001 inch "Kapton" film (18 x 18 inches)

D.4.1.20 Polyurethane foam (18 x 18 x 1 inches)

D.4.1.21 "C" clamps - 8 each

D.4.1.22 Aluminum Plate (18 x 18 x 1/4 inches)

D.4.1.23 Methyl Chloride

D.4.1.24 Soldering/Bonding Machine 47212158

D.4.2 PROCEDURES

D.4.2.1 Module Assembly

a. Align a row of five (5) cells as described for soldered modules in operation D.3.2.1 of this appendix, and remove from the fixture.

NOTE: Repeat this operation until all five rows of cells are made. Since the cells are bonded face down in the assembly fixture, the alignment of cells is greatly facilitated by performing this operation for individual rows of cells, face up before final alignment of the rows in the bonding fixture.

b. Clean the cell tabs by wiping with a fluorocarbon solvent such as "Gensolv" or "Freon."

c. Mount a row of (5) cells face down in the assembly fixture. Align the edge of the plastic (-) tabs along line 1 of the layout pattern on the assembly fixture (Figure D-8) and as shown in Figure D-9.

d. Secure the cells into position with pressure sensitive tape. (Figure D-9a)

e. Fold the copper (+) tabs using a "T" square placed along line 2 of the assembly fixture (Figure D-8) and as shown in Figure D-9b.

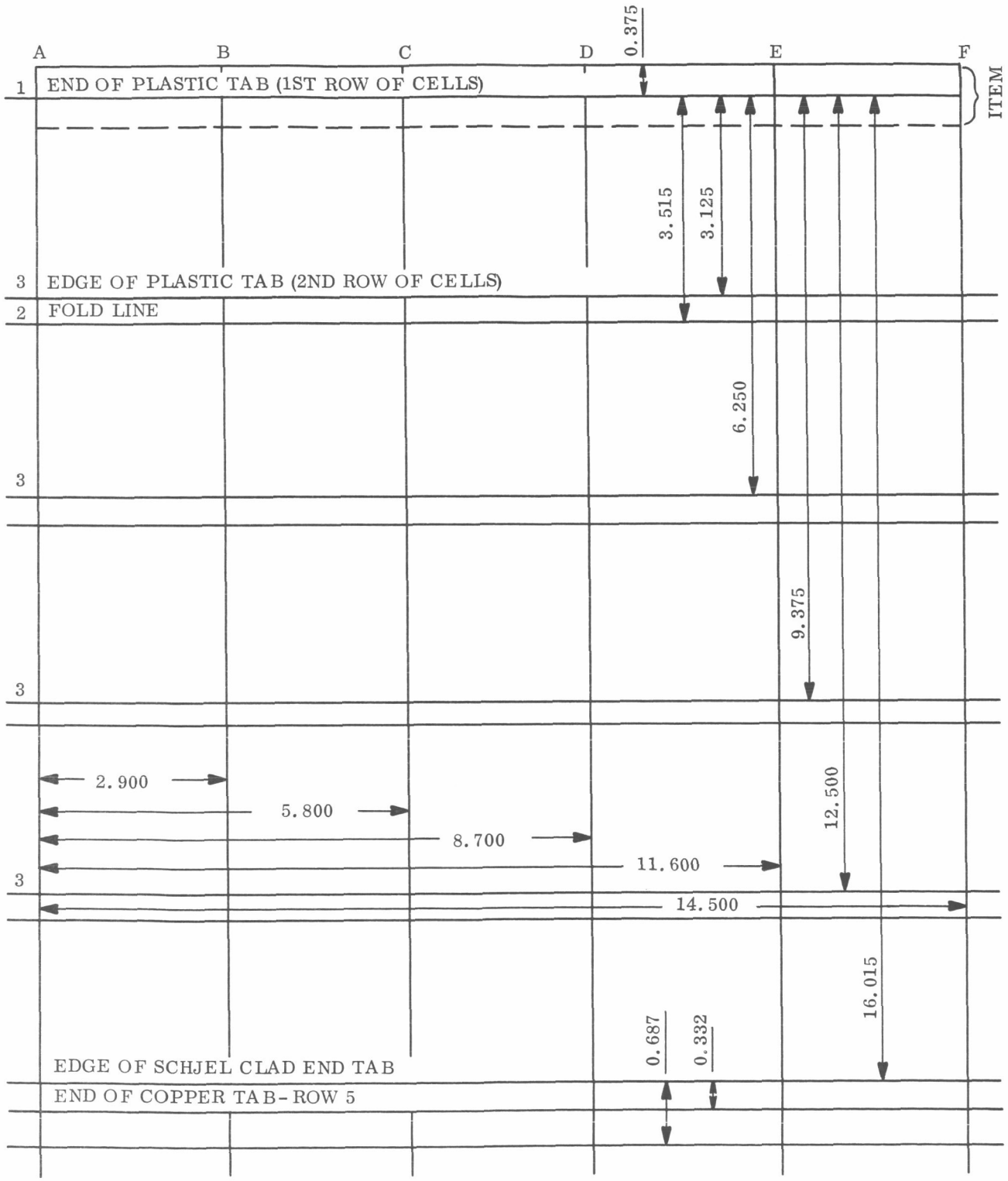
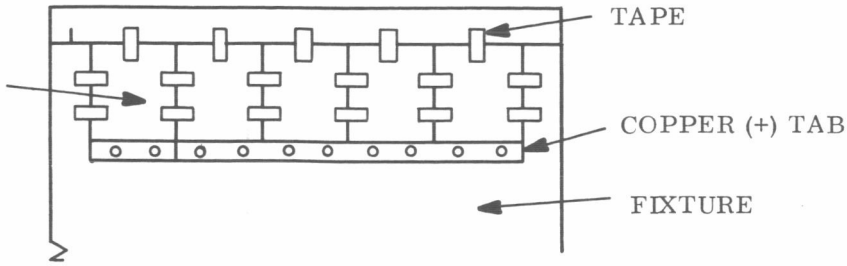
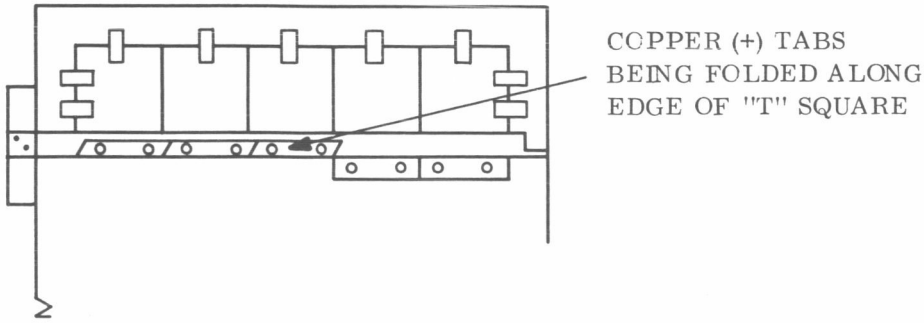


Figure D-8. Module Assembly Fixture, Bonded Module

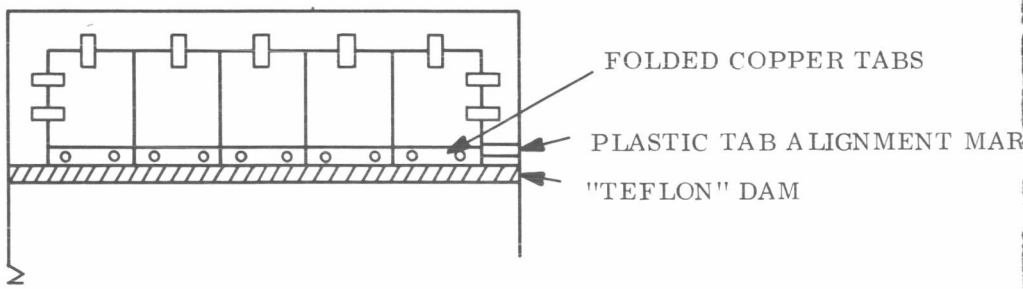
CELLS
(ACTIVE SURFACE
DOWN)



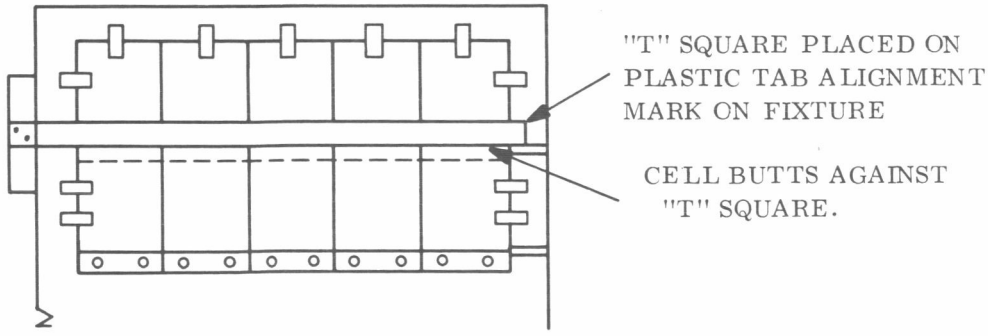
a. CELL ALIGNMENT (1ST ROW)



b. FOLDING POSITIVE TABS

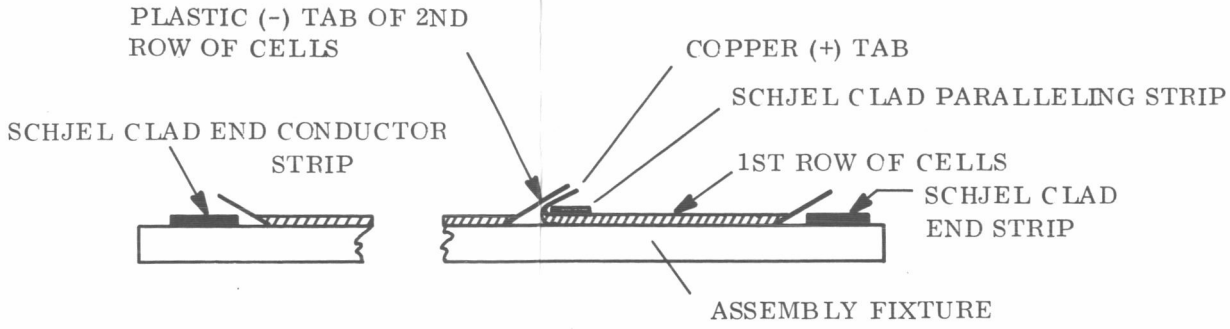


c. PLACEMENT OF "TEFLON" DAM

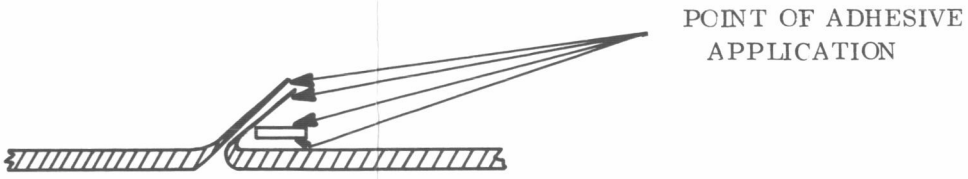


d. CELL ALIGNMENT (ADDITIONAL ROWS)

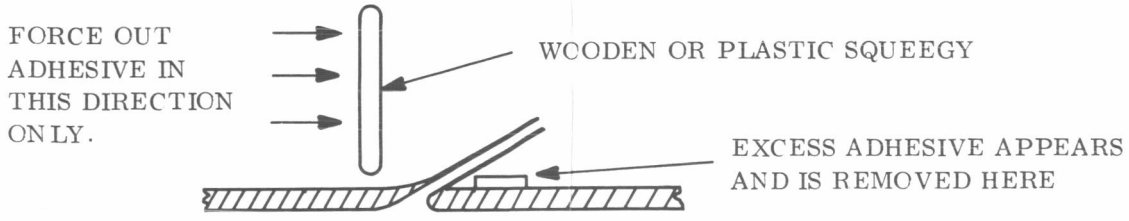
FOLDOUT FRAME 1



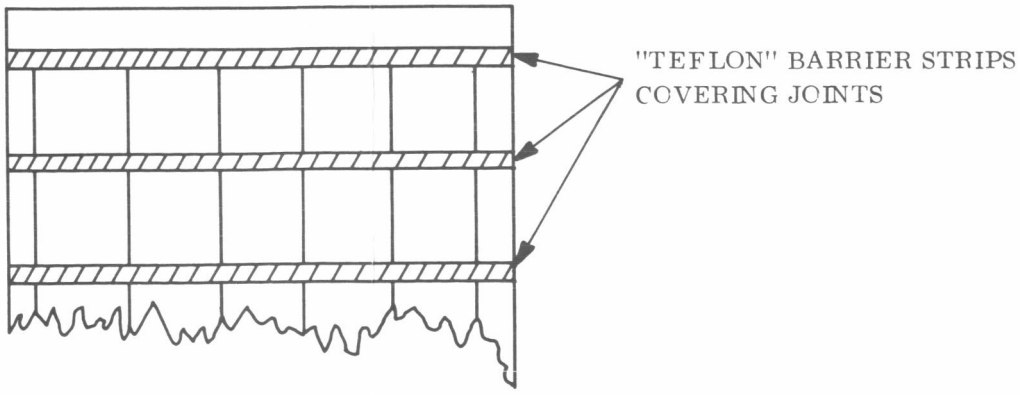
e. END VIEW SHOWING PARTS PLACEMENT



f. END VIEW SHOWING POINTS OF ADHESIVE APPLICATION



g. PROCEDURE FOR REMOVAL OF EXCESS ADHESIVE



h. APPLICATION OF "TEFLON" BARRIER STRIPS

Figure D-9. Cell Assembly and Bonding Steps for Fabricating Conductive Epoxy-Bonded Modules

FOLDOUT FRAME 2

f. Clean exposed tabs with fluorocarbon solvent.

g. Apply a teflon dam along the edge of the fold. (Figure D-9c).

NOTE: The dam consists of 1/2 inch wide masking tape overlaid with a 1/2 inch wide strip of "Teflon" tape.

h. Repeat steps c through g for each additional row in the module.

NOTE: The second and successive rows of cells are aligned so that the negative (plastic) tabs are over the folded copper tabs and along line 3 on the assembly fixture (Figures D-8 and D-9d).

i. Lift the first row of copper tabs and insert a 3/16 inch wide strip of Schjel Clad within the fold (Figure D-9e)

j. Repeat step i for each row of cells.

k. Place an 11/16 inch wide strip of Schjel Clad at each end of the module as shown in the module control drawing 47d214515, Figures D-1 and D-9e.

l. Secure strips to fixture with pressure sensitive tape.

D.4.2.2 Adhesive Preparation

a. Mix the SMRD 745 Part A by stirring with a spatula for 1 to 2 minutes.

b. Weigh 1.0 parts by weight of the SMRD 745 Part A in an unwaxed paper cup or beaker.

c. Add 0.14 parts of SMRD 745 Part B and stir.

d. Add 1.14 parts of "Alcan" silver flake MD 755 to the SMRD 745 and mix thoroughly.

D.4.2.3 Adhesive Application

a. Apply a thin coat of conductive adhesive using a soft bristle artist brush to all the faying surfaces within the bonded joint. See Figure D-9f.

b. Squeeze out excess adhesive using a wooden or plastic tongue depressor or squeegy as shown in Figure D-9g.

NOTE: This is a critical operation and must be done very carefully to prevent contamination of the active surface of the cells. Work the adhesive forward only by applying pressure away from the open end of the joint and moving the squeegy toward the joint edge. See Figure D-9g.

c. Remove squeezed out adhesive with cotton swabs.

D.4.2.4 Fixturing for Curing

a. Place a 1/2 inch wide strip of "Teflon" (nonstick) tape over each joint. See Figure D-9h.

b. Place a sheet (0.001 x 18 x 18 inch) of "Kapton" over the assembly.

c. Place the polyurethane foam pad on top of the "Kapton" sheet.

d. Place the 1/4 inch thick aluminum plate on top of the foam pad.

e. Secure the sandwiched assembly using "C" clamps tightened to depress the foam to approximately 1/2 its original thickness. See Figure D-10.

f. Place the assembly in a 150^{O}F air circulating oven and cure at temperature for 16 hours.

g. Remove assembly from oven and cool to room temperature.

h. Remove the bonded module from the assembly fixture.

i. Remove adhesive contamination from cell surfaces by carefully wiping with cotton swabs moistened with methyl chloride.

D.4.2.5 Application of "Kapton" Back-up Strips

The back-up strips are applied only to the cell butt joints in a bonded module. This is accomplished using the solder-bond machine and the procedures described for soldered modules (Section 3.3 of this appendix).

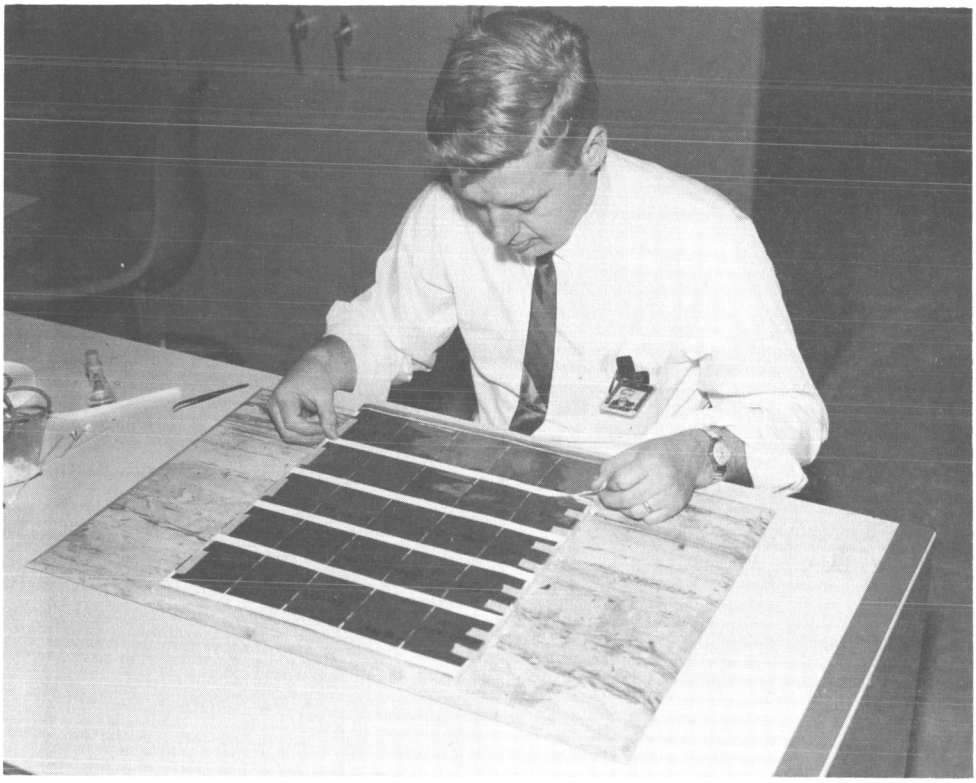


Figure D-10. Curing Fixture, Bonded Module